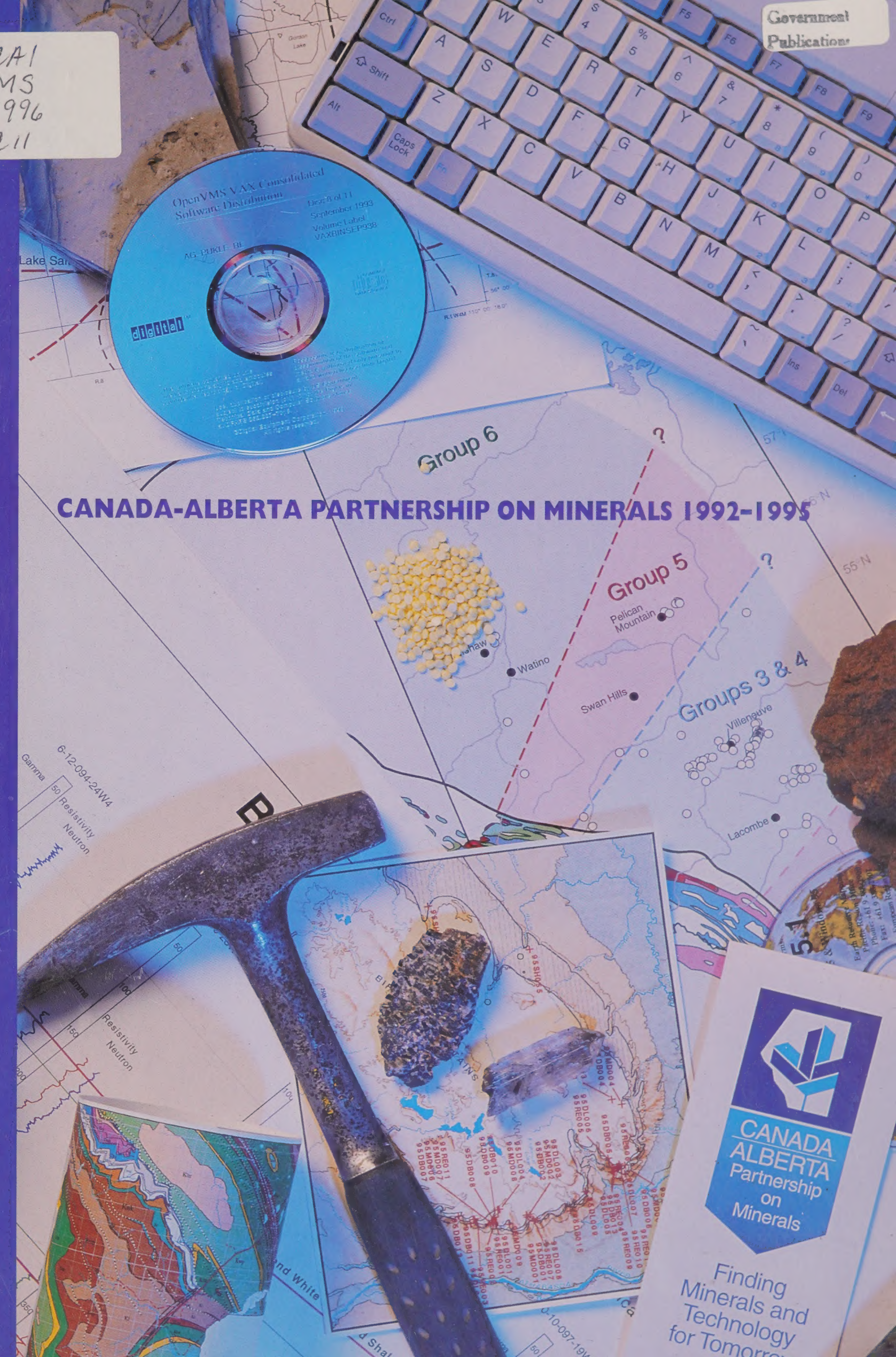
PROGRAM SUMMARY

CANADA-ALBERTA PARTNERSHIP ON MINERALS 1992-1995



Canada-Alberta Partnership on Minerals

1992–1995

Program Summary

ISBN 0-7732-0944-1

To: The Honourable Patricia Black, MLA
Minister of Energy
Edmonton

The Honourable Anne McLellan, P.C., M.P.
Minister of Natural Resources
Ottawa

Honourable Ministers:

We have the privilege of presenting the Summary Report for the Canada-Alberta Partnership on Minerals, 1992–1995. The report includes a summary of the accomplishments resulting from this program, as well as an account of all funds spent on the program including those funds spent during the wrap-up year, 1995–96, by both levels of government.

Respectfully submitted,

Co-chairman
Canada-Alberta Partnership on Minerals

Co-chairman
Canada-Alberta Partnership on Minerals

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Project Listing

Project no.

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Preface

. Canada-Alberta Partnership on Minerals became effec- pril 1, 1992 and was supported by the Alberta and fed- nments according to terms specified in an agreement 1 October 8, 1992. Commonly referred to as the a-Alberta MDA, or MDA (for Mineral Development its purpose was as follows:

- oaden and diversify the economic base of Alberta by eloping and enhancing the non-petroleum mineral
- the geoscience database and understanding of Alberta's geology;
- rt research and development to increase productiv- efficiency of non-petroleum mining and minerals and to address environmental concerns associat- with these activities;
- identify, document and promote opportunities for non- mineral development;
- to encourage private sector investment in the development of non-petroleum mineral resources;
- to enhance recognition of the role and contribution of both the federal and Alberta governments with respect to the mineral industry and Agreement activities; and
- enhance the appreciation and awareness of the mineral sector's contribution to Alberta.

These objectives were met through collaborative project nning and implementation by all interested parties: the pri- te sector; the research community; universities; and the two levels of government. Then, funding was provided by both levels of government to appropriate research projects brought forward by various proponents. Additional funding was provided by private-sector partners.

Research proposals were ultimately presented for approval to a Management Committee representing both governments, which was responsible for administering the MDA program and approving all program expenditures. The objective of this committee was to ensure that the necessary minerals-related database and technologies be available in a timely manner to permit the full economic potential of the mineral resources of Alberta to be realized.

The Management Committee was assisted in its task by technical committees assigned to oversee specific aspects of the MDA program. Each technical committee comprised representatives from the federal and Alberta governments, and most had an industry advisor to provide an industry perspective to the MDA. Committees were set up in this manner to ensure that projects in each component were well designed and would enhance Alberta's mineral knowledge base and technical capability.

These technical committees were concerned with geoscience, technology development, economic development, public information, and program evaluation and administration. They were responsible for assessing the merits of proposed projects and for overseeing the progress of those that were approved.

In addition to the activities of the various committees, the day-to-day administration of the MDA was carried out by a Secretariat representing the federal and Alberta governments.

Introduction

The Canada-Alberta Partnership on Minerals (MDA) was initiated in 1992 because it was believed that Alberta possesses significant metallic and industrial mineral resources, but much of this potential had never been defined. This was because most of the past economic activity in the province has been focused on oil, gas and coal exploration and development. Therefore, only limited exploration for, and development of, these other resources had taken place. Consequently, little publicly available information existed on these resources, whether in the form of geoscience data, maps, reports or assessments.

Conversely, in those areas of Canada where mineral exploitation is currently a major activity, exploration programs are stimulated and guided by baseline geoscience information that is in the public domain. It was suspected that as long as Alberta remained without such information there would be little incentive for the minerals industry to increase its exploration effort in the province.

The MDA sought to redress this deficiency and broaden Alberta's economic base. This was done through several activities. They were: a geoscience program specifically geared to metallic and industrial minerals; the development of appropriate technologies to extract these resources economically; economic analysis to evaluate market opportunities; and a program of public awareness to inform Albertans about the contribution that the minerals industry makes to the economy.

The MDA was the result of regional development initiatives by the federal government through Economic Regional Development Agreements and Western Economic Partnership Agreements. This agreement, the first MDA within Alberta, was intended to provide a fund of $10 million over a period of three fiscal years. During the course of the MDA, fiscal restraint by both levels of government reduced the total expenditures to $8.4 million. Within each component, projects were funded by either the federal or Alberta government. In addition, many projects received support from the private sector.

Natural Resources Canada (NRCan) and the Alberta Department of Energy were responsible for implementing separate provincial and federal projects within each component. On behalf of Alberta, projects were undertaken by the Alberta Geological Survey and individual research and geoscience companies. The Canada-funded projects were carried out by the Geological Survey of Canada, the Canada Centre for Mineral and Energy Technology (CANMET), and individual research companies. Private researchers were also retained for contract work under the two surveys.

Industry had three ways to participate in the MDA:

- as contractors to NRCan's Geological Survey of Canada;
- as contractors to the Alberta Geological Survey; and
- as performers of projects awarded by the Alberta Department of Energy.

Background

1993, the value of mineral production in Alberta
l $18.6 billion, making Alberta the leading mineral-pro-
province in Canada. However, approximately 96 per
his production was attributed to fossil fuels.

than 40 non-hydrocarbon minerals are known to
lberta, yet in 1991, less than one-half these were
luced. Gold and industrial minerals accounted for less
per cent of total mineral production, or about $337
production value (including sulphur).

lberta's geological formations have the potential for
its of metallic minerals, such as gold, silver, lead, zinc,
lium, titanium, nickel, zirconium, uranium and
minerals occur mainly in the Canadian Shield (gold,
zinc, copper, uranium and nickel), in the Cordillera
l, zinc, magnetite, iron and titanium), in the oil
vanadium, nickel, titanium and zirconium), and in
r deposits in the Plains.

uction of precious stones is also minimal in the
mmolite is the only semi-precious stone known to
rta, where it is produced and processed. However,
nce of kimberlite pipes in Saskatchewan and the
st Territories has led to speculative interest in Alberta
mond prospecting near the Canadian (Precambrian)
nd in the Foothills and Plains, particularly in the Peace
area.

Currently, the most important non-hydrocarbon minerals
berta are industrial minerals, such as sulphur, limestone,
lcium chloride, clay, sodium sulphate, sand and gravel.
thers present in the province, but not currently produced, are
ypsum, dolomite and phosphate. An estimated 500 people
rk in the exploration and development of Alberta's non-ener-
minerals, largely in the industrial minerals sector.

he mining, beneficiation, production and shipment of industrial minerals form a large and important part of Alberta's economy. In addition to this primary industry, plants that use industrial minerals as raw materials account for approximately six per cent of total manufacturing employment and represent about 6.5 per cent of all manufacturing industries. Such industries as cement, ready-mix concrete, clay products, salt (chloralkali) and lime are important for Alberta's economic growth, and aggregate is an essential material for constructing roads, dams, bridges and buildings.

While the established industrial minerals industry is better developed than the metallic mineral sector, the former still requires assured and increasing supplies of raw materials to maintain existing markets and develop new markets for current products. In addition, opportunities exist to apply new technology to existing materials to generate new and/or improved products.

With the signing of the Mineral Development Agreement, it was expected that the resulting research would provide the necessary data to determine mineral potential and stimulate related industrial expansion.

Much of the rationale behind the MDA was based on the belief that there is significant potential in Alberta for the discovery of unknown or unrecognized mineral resources that could provide the basis for industrial diversification, expansion and import substitution.

Regardless of the resource type, detailed geological and resource studies are essential to provide the data necessary to substantiate mineral potential and attract industrial exploration interest.

Before the MDA, geological information was incomplete even for those minerals used in established industries. The quantity, quality and distribution of sand (silica and construction), gravel and limestone, for example, were unknown for many parts of Alberta even though detailed geological and resource information is essential to ensure a future for these industries. Such information would also form the basis for expansion into currently unexploited regions.

Fundamental geological knowledge is a prerequisite for the discovery of new industrial mineral resources. Significant potential is known, for example, for gypsum, placer minerals (garnet, magnetite, silica sand) and formation waters (calcium/magnesium), but published geological information and data were too limited to make satisfactory economic evaluations. For many of Alberta's more than two dozen known industrial minerals, detailed maps and reports were lacking altogether.

Resource profiles are an example of the type of information needed by industry. They provide a solid basis for assessing the status of individual commodities in terms of geology, technology and marketing. Such analyses can be used to identify information gaps and opportunities.

With this as a background, the MDA Management Committee set out to support new and established industrial mineral industries, as well as new or continuing metallic exploration. They did this by funding research studies which: (1) provided a solid base of geological and resources-inventory data to help ensure resource supplies; (2) supported technology research into mining and processing opportunities; and (3) evaluated market potential for current and potential products.

Program Overview

Geoscience Component

The geoscience studies supported by the MDA program can be divided into two groups: those concerned with metallic minerals; and those involving industrial minerals. Within each of these groups, geoscience activity tended to be focused on selected regions of Alberta that either held potential for discoveries, or had not been well studied and mapped in the past. This is particularly true for metallic minerals. Therefore, many studies took place in the southern and southwestern corner of the province, as well as in the northeastern portion, which is dominated by the Canadian Shield. Other studies, however, encompassed many areas of Alberta, and some covered most of the province.

Metallic Minerals

In southwestern Alberta, two investigations of the Southern Alberta Rift were undertaken to locate and document features that might indicate metallic mineral deposits. This area was targeted because rift zones are often hosts for base metals and precious metals in other parts of the world. The first study found that good potential exists for the discovery of several types of deposits.

The second study found significant evidence that rift activity has occurred over several periods of time, and other information helps define the inferred margins of the rift, particularly its southern margin. The study produced hard evidence that rift-related events are preserved in rocks of the Clark Range of mountains which encompasses Waterton Lakes National Park and extends northwesterly along the border between Alberta and British Columbia.

It is likely that lead-zinc, nickel-zinc and copper-silver deposits are present within or near the Southern Alberta Rift.

Another feature of interest in southern Alberta is the Crowsnest Volcanics. It is a linear north-south zone of extrusive igneous rocks located east and west of Coleman in southwestern Alberta. The zone may host gold, base metals and rare earth elements. A study was undertaken to determine the volcanological, petrological and mineralogical characteristics of the Crowsnest Volcanics, but it was concluded that any quantities of gold or base metals hosted by these rocks are not economic.

The close proximity of the zinc-lead deposit at Pine Point, NWT to the northern Alberta border has intrigued geologists for years. It is suspected that the conditions responsible for this deposit may have created a similar, as-yet undiscovered deposit in Alberta. It has been suggested that the Pine Point deposit may have arisen from minerals that were deposited either from formation waters or hydrothermal fluids. To pursue this concept, one investigation examined the formation waters of northern Alberta to determine whether they could be related to the Pine Point deposit. It was concluded that the formation waters must be ruled out, but basement faults that might have been conduits for hydrothermal fluids are present, as are appropriate aquifers for these fluids to pass through.

In a second study relating to zinc-lead deposits, 675 samples of cores from 61 wells in northern Alberta were examined for 30 elements. No significant evidence of lead-zinc mineralization was found, although some interesting anomalies were observed that merit further examination.

The Canadian Shield that underlies much of northeastern Alberta has been a source of minerals in other provinces, and very likely will also yield economic deposits in Alberta. One study of this area sought to reveal information that would explain the tectonic evolution of rocks in northeastern Alberta. It was thought this might lead to the discovery of mineral deposits, particularly shear-zone hosted gold. Indeed, a previously undiscovered shear zone was found, and some strata worth detailed investigation were identified. Also, the results of isotope studies showed that this technique should be useful for diamond prospecting. The project also generated 12 maps of the Shield geology.

In another study, promising areas for gold and other deposits in the Canadian Shield were investigated in greater detail. Nineteen mineral occurrences were deemed to indicate the potential for economic deposits, particularly of gold and base metals.

Previous geological studies of the Canadian Shield resulted in a collection of more than 11 000 rock samples, most of which had not been sorted or catalogued, nor were they readily available for further analysis. Thus, one undertaking in the MDA program involved organizing these rocks according to their sample location, analyzing some, and then producing maps based on the new information. Because of limited funding, only a minor portion of the rock collection was catalogued in this manner. Both the maps and the rock collection were used to support other MDA projects.

Since uranium is mined in the Saskatchewan section of the Athabasca Basin, a feature overlying part of the Canadian Shield, it has been generally assumed that similar geological conditions prevailing in the Alberta portion of the basin may indicate good prospects for finding economic deposits of this mineral and polymetallic minerals. An investigation confirmed that such favourable conditions do exist. Rocks in the Alberta portion of the basin contain polymetallic mineralization of ura-

nium, nickel, arsenic, cobalt, molybdenum and zinc, and elevated values of chromium were found in rocks from the study area.

Little is known about the geology of that portion of northeastern Alberta which encompasses Fort MacKay and the Marguerite River area. Because the area is situated on the edge of the Western Canada Sedimentary Basin, is underlain by Canadian Shield rocks and is discharging large volumes of brines from the subsurface, it should be a promising area for mineralization. A detailed study added considerably to the information that is known for this area. Furthermore, the exploration data suggest that favourable conditions exist in the area for several base- and precious-metal deposits.

One of the techniques that has become increasingly accepted for finding mineral deposits is till geochemistry. It is especially suitable when working in flat and rolling terrain. Thus, one project carried out on the Canadian Shield employed this technique to generate the data needed to produce several maps. They show ice flow patterns that can be used to point to the source area of minerals transported by ice action.

Airborne surveys are another exploration technique. One such survey was carried out using a gamma-ray spectrometer, a proton precession magnetometer and a Very Low Frequency-Electromagnetic (VLF-EM) sensor. Survey data resulting from the study were used to produce colour geophysical maps, a geological compilation and mineral occurrence map, and a complete set of stacked, multiparameter profiles for each flight line.

Past experience has shown that lake-sediment geochemical data can indicate broad, regional trends of mineralization. [illegible] are a cost-effective way of quickly evaluating the mineral potential of an area and stimulating mineral exploration activity. Thus, a lake-sediment and water geochemical survey was conducted over a 22 100 km^2 area of northeastern Alberta. Data listings and statistics were prepared, and two types of maps were produced: a sample-location map showing background geology; and a small map for each element and its concentration. Furthermore, the data indicated that a moderate potential for uranium exists, and there is some potential for gold.

The various investigative techniques used throughout Alberta generated a considerable volume of data. To make this information easily accessible for future exploration, a process was developed to integrate all the new data with existing data in a single database. The results will be made available through the Alberta Geological Survey.

While most investigations in both southern and northern Alberta considered possible locations of gold deposits, the only significant quantities of gold found thus far in Alberta have been in placer deposits. One study that encompassed both metallic minerals and industrial minerals was concerned with Tertiary-age and other preglacial deposits that produce most of the high-quality mineral aggregate and placer gold in Alberta. It was believed that the knowledge gained from this study could aid in exploring for gold, diamonds and aggregate. Thus, 221 Tertiary and preglacial age sand and gravel deposits throughout Alberta were delineated and described. Ninety-five of these deposits were found to have either known or probable potential for mineral aggregates. Two areas warrant further examination for diamonds: one near Edmonton; and another near Peace Riv[illegible]

The exact origin of the placer gold found in the North [illegible]katchewan River near Edmonton has never been determined. Nonetheless, the general source of these "paleoplacers" is believed to be in the mountains. Therefore, one stud[illegible] on gathering rock samples from 92 sites in the southern half o[illegible] the foothills segment of the North Saskatchewan Ri[illegible] [illegible] slightly higher concentrations. They might indicate sites of future investigations.

[illegible]ation of sand and gravel [illegible]eserves or potential placer gold deposits is to conduct heavy [illegible] combined with the use of ground-penetrating radar. In one project, these techniques were [illegible] areas of the North Saskatche[illegible] [illegible]IcLeod and Peace river systems. Ground-pene[illegible] [illegible] for stratigraphic mapping of [illegible]nes in gravels. While the study was under way [illegible] operators and industry contractors [illegible]ology. Overall, the [illegible]seline information on the dispe[illegible] [illegible] patterns of gold, platinum group elements [illegible]

[illegible]ploration activity in western Canada bein[illegible] dedicated to the search for diamonds, several MDA proje[illegible] [illegible]fforts. Of conside[illegible] importance was one project that provided a summary of all the [illegible] diamonds at the time [illegible]n, and Alberta's potential for hosting [illegible]hem.

[illegible]nother project, carried out in southern Alberta, aimed to [illegible]ore information about rocks having good potential for [illegible]liamonds. Seven minette bodies in the Sweetgrass Hills [illegible]l to be discrete, small volcanic vents. [illegible]f indicator-mineral compositions for Alberta [illegible]nberlites is being created for comparison with results from [illegible]her kimberlite studies in North America. An aeromagne[illegible] [illegible] was also carried out in the Cypress Hills to provid[illegible] [illegible]porting information for diamond exploratio[illegible]

In another project, information was gathered about the till characteristics, geochemistry and the presence (or absence) of diamond-indicator minerals in southern Alberta. A similar study was carried out in northern Alberta, and both projects used the same sample-collection and analytical methods. These were the first systematic studies of indicator minerals, geochemistry and sediment composition. The findings from the study in southern Alberta should provide a useful guide to any locations of diamond-bearing bodies. The northern Alberta study showed that high concentrations of some elements tend to be localized and appear to be related to the areas where the Shaftesbury Formation outcrops. Although the distribution of diamond-indicator minerals was irregular, some trends appear to be evident.

Supporting the northern Alberta investigation was a detailed examination of the surficial geology, the Quaternary stratigraphy and glacial history of two areas. This work provided evidence of the glacial history of the areas, as well as geochemical and mineralogical data that will be useful for future work.

The oil sands area of northeastern Alberta was also the scene of one geoscience investigation. In a preliminary study, the potential for finding and recovering minerals and metals associated with oil sands was examined. If such recovery is feasible, this could make oil sands operations even more economic. The study results showed that understanding the depositional environments that existed when the formations were developing is an excellent method for locating elements, and it is possible to predict where the elements of interest are likely to be.

Industrial Minerals

Forty-two industrial minerals that exist in Alberta are being exploited or might be exploited, but detailed geological, technical and economic background reports had not been prepared for all these minerals before the MDA program began. Consequently, commodity profiles were produced for three minerals in one project, and three previously released profiles were re-issued.

Cement and lime made from Alberta limestone deposits are worth more than $120 million annually. Because limestone supplies are dwindling and demand is rising, the objective of one project was to conduct comprehensive resource analyses of limestones in Alberta. As a result of this investigation, at least one new location in the Yellowhead corridor and several in the David Thompson corridor show some promise as potential sources of industrial limestone.

These two mountain corridors, as well as the Crowsnest Pass, have yielded numerous industrial minerals in the past, but they have not been well mapped for mineral occurrences. Furthermore, these corridors are believed to host some of the minerals that are required by newer industries, such as pulp and paper. Thus, the principal objective of another geoscience project was to map the mineral resources of the Crowsnest, David Thompson and Yellowhead corridors.

While magnetite is the only metallic mineral present in the Crowsnest corridor, several promising sites for limestone, dolomite and other industrial minerals were found. Also, maps of the four corridors were prepared at a scale of 1:100 000.

Alberta's mineral aggregate industry annually produces 45 million tonnes, making Alberta fourth in total production in Canada and second in the production of sand and gravel. Unfortunately, these resources are being consumed twice as fast as new ones are being found. One study undertook to begin gathering the data necessary to make informed, resource-management decisions about mineral aggregate. It identified a number of issues that need to be resolved in the next 10 years.

Formation waters are used in Alberta to supply some commercial mineral-extraction operations, but little information is available on the areas and stratigraphic intervals in the sedimentary succession in Alberta that contain economically significant industrial minerals dissolved in formation waters. Therefore, one geoscience project was undertaken to study these brines, with particular emphasis on calcium, magnesium, potassium, lithium, iodine and bromine. Potentially economic concentrations of calcium, magnesium and potassium were found in central Alberta and southern Alberta strata. Bromine is also present in high concentrations, and strata in west-central Alberta contain formation waters having economic concentrations of lithium.

While the brine investigation was under way, a complementary study was made of evaporite rocks throughout the province. This resulted in a surprising discovery of a new type of mineralization in the Fort MacKay area. It appears that oxidized, chloride-rich brines played a part in mobilizing and transporting metals, such as gold, silver and copper. This discovery provides new opportunities for research into mechanisms of metal transport and deposition in geological environments previously believed to be unpromising. Since the initial discovery, several companies have spent approximately $7 million conducting additional exploration in the Fort MacKay area.

Having supported more than 30 geoscience research projects, the MDA program generated a considerable volume of new information. While it is possible to access and read the individual project reports, this is a time-consuming way to obtain the needed information. An alternative is offered by another project, in which a computerized information system was created that assimilates, stores and makes accessible geoscience information generated by the MDA program. Data can

be printed or copied to disk, and maps based on any set of data can be generated. Any map that can be displayed can be printed. Data sets from the geoscience projects continue to be added to the database.

Technology Development Component

Most of Alberta's known gold exists in small flakes called "flour," and is found in the sediments of major rivers or gravel that was deposited by ancient rivers. Much of this flour gold is so fine it passes uncollected through conventional collection devices and is lost. It was determined that an Alberta-developed adsorption method called the Envi-Tech Adsorption Process might be capable of recovering this fine gold. Consequently, two projects were supported by the MDA program to test and develop this technology. Overall, the two projects proved that selective adsorption can recover virtually all the gold present in placer deposits, hard-rock deposits, limestone and lamproite. The recovery efficiency using placer deposits was approximately three times that of sluicing methods now used. Operating conditions were established in small and larger-scale laboratory mixers, and sufficient knowledge was gained to design pilot-scale processors.

Given the commercial potential of the Envi-Tech process, a project was undertaken to generate some preliminary engineering design and cost data for a commercial-scale operation. While only preliminary data were available at the end of the MDA program, they indicated that a 140 per cent return on investment before taxes was possible when using the Envi-Tech process in an expanded sand and gravel plant capable of producing 11 500 ounces of gold each year.

In a separate project, it was found that the Envi-Tech process has a negligible effect on the environment. This contrasts sharply with conventional gold-extraction processes that use cyanide. Tests showed that organic and inorganic substances in wastewater from the Envi-Tech process were well within the allowable environmental constraints, and the liquid discharge was not toxic.

Since diamond exploration in Alberta has recently become more active than at any other time, there is a growing requirement for a reliable and inexpensive method for extracting and measuring minerals that often indicate that diamonds are present. Since the most common method for extracting and quantifying these minerals is expensive and uses hazardous chemicals, a project was undertaken to assess the effectiveness of a device called the Wilfley Half Table. It was concluded that both the conventional and Wilfley Half Table methods produced similar quantities and qualities of indicator minerals, thus demonstrating that the Wilfley Half Table was suitable for the task

When the MDA program began, no laboratory existed in Alberta for the purpose of processing samples thought to be diamond bearing. Therefore, the objective of another technology-development proje [illegible] and analytical facility. Th[illegible] determining the characteristics of field samples, ascertaining the requirements for samp[illegible] preparation, evaluating processing equipment and miner[illegible] tion equipm[illegible] and a mineral-picking sys[illegible] lyzing mineral [illegible]

[illegible] aluminum chloride and other chlorides from raw ma[illegible]

als that are found in Alberta and other parts of western Canada. These chlorides can then be further processed to recover aluminum, other metals and various commercially valuable products. The objective of one technology-development study was to examine various potential raw materials available in Alberta for their suitability in the Toth process, and then perform cost-benefit analyses for constructing a commercial-scale facility in Alberta.

It was found that the aluminum content of oil sands fine tailings could support two 350 000 t/y aluminum smelters. Sands associated with these tailings are sufficiently high in titanium that they could be used to produce titanium tetrachloride, a precursor of pigment-grade titanium dioxide. Also, a comparison of capital and operating costs with projected revenues of a chloride plant indicates that attractive returns on investment are possible under several circumstances. It was recommended that a chloride plant be built.

High-strength and light-weight building blocks made from a product known as aerated concrete are used in Europe in place of conventional concrete in various applications. The material is made from silica, cement, lime and water. The resulting porous structure gives rise to its characteristics. Since a material called zeolite is porous in its natural state, it was believed that incorporation of this material in an aerated-concrete formula might make a superior product. Preparing and testing this product, and determining the sources in Alberta of the necessary raw materials, were the principal objectives of one study.

Several aerated-concrete formulations, using zeolite combined with small quantities of silica, were successfully prepared. Tests showed the product could be made over a range of desirable compressive strengths. Although zeolite has not yet been discovered in Alberta, the other ingredients are abundant in the province.

Economic Development Component

The MDA-supported projects that aimed to help develop and promote Alberta's mineral sector were included in the Economic Development component.

The largest project in this component was an overview of the worldwide system for marketing diamonds. It covered all aspects of the business, from a summary of existing diamond mines, to preparing raw diamonds for the market, to the tightly controlled marketing process, itself. Also, valuable information was provided about the marketing infrastructure that ought to be in place when Canada's first diamond mine opens in the next few years.

Attempts have been under way since 1988 to quarry a red granitic pluton measuring 24 km by 6.5 km that lies northwest of Fort Chipewyan. While the rock is suitable as ornamental building stone, standard-size building blocks could not be recovered because the blocks broke into smaller pieces. The objective of one project was to investigate the various markets for crushed granite products and determine if some type of granite-crushing operation would be economically viable. The study showed that the most promising option involved making agglomerated tiles, and this could be profitable by using either waste granite from an existing operation or by using a new quarry operation for the specific purpose of recovering crushed granite.

Although mineral aggregate is the most valuable, non-energy mineral produced in Alberta, there is no common database of information on the sand and gravel resource which various government departments could use when making resource-management decisions. Therefore, a project was undertaken to prepare a mineral aggregate database, which could then be used to construct resource maps or be integrated with data on other land-use issues. A database was constructed by digitizing all the available information on Alberta sand and gravel deposits. This information was then used to prepare 15 1:250 000 scale maps that cover approximately one-third the total area of Alberta.

Substantial limestone deposits are located in western Alberta, allowing industries based on limestone to have become well established in the province. The objective of one study was to identify new opportunities for limestone so the industry can grow. It was found that most new markets for Alberta limestone will likely be in Alberta because it is too expensive to ship it outside the province. Some new market niches include limestone rock products, the pulp and paper industry, air pollution control equipment, and more lime use in neutralizing lakes that have been acidified by acid rain.

Naturally occurring materials that contain humic acid are desirable for agriculture, reclamation and the drilling industry, but Alberta's known resources are not being as well used as they might be. One such material is called humalite, and an MDA-supported project was undertaken to provide an overview of Alberta's resource and some indication of markets for this material. It was found that Alberta's extensive agricultural activities and a growing need for mine-site and well-site reclamation, could consume 45 000 tonnes a year of Alberta-supplied humalite.

Studies in the geoscience component indicated that economic quantities of certain salts may be present in brines found at various locations in Alberta. In one economic-development study, an investigation was made to determine the economic viability of recovering calcium and magnesium chlorides from

these brines. It was concluded that opportunities could arise in Alberta for calcium chloride use in newsprint de-inking and the manufacture of sodium chlorate, which is a precursor to chlorine-free bleaching agents used in the pulp and paper industry.

In two other projects in this component, funds were provided to support the development of a new strategic vision for the mining industry, and to promote aboriginal involvement in the Canadian mining industry.

In one project, information about the MDA was made available by creating a homepage on the World Wide Web of the Internet. Persons accessing this homepage will find a logo, a statement of purpose for the MDA, a list of contributors, links to a list of projects and links to other on-line resources arising from the MDA.

Public Information

No research program would be complete without mechanisms for disseminating the research results to people who n[illegible] them. This information dissemination was accomplished by [illegible]ious means. They included publications, a newsletter, news releases, advertisements and the use of display booths at conferences. In addition [illegible] presented papers and poster sessions at technical conferences that enhanced the public profile of the [illegible]

Evaluation and Administration

[illegible] ogram supported by public funds, a process for [illegible] the program and careful [illegible] and funding are th[illegible]

Program Projects

Organization

Individual projects within the MDA program were assigned to five sub-programs. Consequently, the project descriptions that follow are grouped into their respective sub-programs.

GEOSCIENCE

Through collaboration with the minerals industry, the Geoscience component focused on both Alberta's metallic mineral potential and industrial mineral resources. Program delivery occurred through a series of projects undertaken in five areas. They were:

- regional mapping for mineral potential;
- Quaternary geology and drift prospecting;
- geochemical and geophysical exploration;
- commodity profiling; and
- mineral information system development.

Regional Mapping for Mineral Potential

Previously, the only detailed maps of metallic mineral resources in Alberta were produced at a scale of 1:250 000 or smaller. This was regarded as insufficient detail to encourage exploration. Also, most of the surficial geology of northern Alberta had not been mapped. Therefore, to stimulate metallic mineral exploration in Alberta, detailed bedrock and surficial geological mapping of selected parts of the province formed an integral part of the MDA.

Quaternary Geology and Drift Prospecting

Most of Alberta's bedrock lies buried beneath surficial deposits of glacial and fluvial origin. Consequently, both regional and local knowledge of the geometry, composition, geochemistry, thickness and stratigraphy of these deposits is paramount to the identification of mineral potential. This is equally important for sediments, the underlying bedrock and the source areas from which these minerals were derived. Before the MDA, many of the Quaternary and Tertiary sequences of Alberta were unmapped, especially in the northern part of the province.

Not only was there a need to integrate exploration studies with bedrock mapping and geochemical surveys, but the hydromechanics and chemistry of aquifers contained within the surficial deposits required attention. Examples of other features that required detailed documentation and analysis included: glacial dispersal trains; indicator minerals; stacked sequences of glacially thrust bedrock; potential placer deposits; and by-product resources such as gold recovered during aggregate mining. All these aspects were addressed in this component of the MDA program.

Geochemical and Geophysical Exploration

Geochemical and geophysical exploration represents the application of contemporary advanced technologies to the pursuit of subtle exploration targets. Regional geochemical and geophysical "backgrounds" often must be established before potential exploration anomalies can be most effectively identified and assessed, even in areas of extensive bedrock exposure. Furthermore, these technologies are often the sole or primary means of evaluating economic potential in areas of little or no bedrock exposure.

It was recognized that geochemical assessment, initially at a reconnaissance level, was necessary on lake and stream sediments and waters, and on the aquifers and materials within the glacially deposited surficial cover. Also, airborne magnetic surveys could be used to enhance or add to the existing regional geophysical data and identify areas for selective fill-in or detailed investigation using a variety of ground-based geophysical techniques. Borehole geophysics might prove to be necessary for characterizing and correlating economically interesting till sequences. All these technologies were used in this component of the MDA program.

Commodity Profiling

Commodity profiles provide the accurate and detailed information on the location, characterization, quantity and quality of minerals that is required by the exploration industry. Consequently, this activity was included in the MDA program and linked to the Technology Development and Economic Development components.

Mineral Information Systems Development

At the outset, it was realized that contemporary, accurate and comprehensive information about metallic and industrial minerals is pivotal to the support and enhancement of mineral exploration and development within Alberta. For example, an immediate and thorough evaluation of the metallogenic potential of the province, based on existing data, maps and reports was necessary to guide the initial selection of field studies.

Furthermore, it was necessary to coordinate continuous gathering and dissemination of results from all activity areas, and this information needs to be available in both published and electronic forms. This activity became a valuable component of the MDA program.

The Geoscience component supported baseline geoscience work which is of benefit to all Albertans. Projects within this sub-program had no confidentiality provisions; all the information is for public dissemination.

Geological Mapping, Prospecting and Sampling of the Southern Alberta Rift

R.A. Olson Consulting Ltd., Edmonton

Project M92-04-002

Southern Alberta is the site of a large rift zone called the Southern Alberta Rift. In other parts of the world, rift zones are often hosts for base metals (such as lead, zinc and copper) and precious metals (such as gold, silver and platinum).

The Southern Alberta Rift (also called the Vulcan Low) is an ancient and long-lived geological feature that trends in a northeasterly direction from southeastern British Columbia into southwestern Alberta and across southern Alberta to the Saskatchewan border. The area is mainly underlain by metasedimentary rocks, and some specific locations feature volcanic and intrusive igneous rocks that range in age from Middle Proterozoic to Tertiary. Metallic mineral occurrences are known to exist in the general area and in adjacent U.S. states, and these have been related to the rift.

Exploration in the Alberta sector has not been carried out for 15 years, since development in much of the area came under the control of the Alberta government's Eastern Slopes Policy. Nevertheless, considering the likelihood of economically valuable mineral deposits in the area, a geological exploration project was initiated in 1992 in the Alberta sector of the rift, covering an area of 7 320 km^2. The objective was to locate and document features that might indicate metallic mineral deposits. This work was complemented by a geochemical survey of the regional stream sediments.

Background

The study area comprises two physiographic regions: the Eastern System of the Western Cordillera, and a small segment of the Interior Plains in the northeast portion of the area. The cordillera component is the most dominant, and it consists of the Foothills and Front Ranges of the Rocky Mountains in nearly equal proportions. While the Foothills are mostly rounded ridges having elevations up to 1 800 m, the Front Ranges are characterized by cliffs whose summits [illegible]

[illegible] occurred in the area since the [illegible] ration found more than 70 [illegible] a northwesterly direction along the Alberta-British Columbia border. Magnetite deposits are known to exist in the Crowsnest Pass and near Pincher Creek, and many other mineral occurrences [illegible] iated. The mo[illegible]

In British Columbia and adjoining U.S. states, several important mineral deposits are known, and most are thought to be related to the Southern Alberta Rift. These include base metal deposits in northern Montana and Idaho, northeastern Washington and southeastern British Columbia, and scattered deposits of copper, gold and other minerals in various locations.

1992 Fieldwork

Given the exploration restrictions placed on portions of the study area by the Eastern Slopes Policy, approximately 23 per cent of the land area could not be explored.

In the remainder of the study area, a field program was carried out from mid-August to mid-October 1992 to find and document features that often indicate metallic mineral deposits. These included: metallic mineral occurrences; alteration; gossans; veining; sedimentary facies changes in association with faults; high-angle faults related to tensional tectonics; and other geological anomalies. Also, a regional geochemical survey of stream sediments was carried out.

Results

Altogether, 164 rock samples were collected from selected mineral occurrences and anomalies. Nineteen metallic mineral occurrences were discovered, and seven previously known occurrences were studied. Sample locations are shown on computer-generated base maps of the area's geology. They are available from the Alberta Geological Survey.

The collected rock samples were analyzed for 31 elements, using a combination of Inductively Coupled Plasma Emission Spectroscopy and Fire Assay/Atomic Absorption. Samples from the newly discovered occurrences assayed up to 227 parts per million (ppm) copper, 184 ppm lead, 798 ppm zinc and 0.7 ppm silver. Elevated concentrations of arsenic, barium, cadmium and molybdenum were also found. Analysis of the previously known occurrences assayed up to 3.48 per cent copper, 12.1 per cent lead, 19.5 per cent zinc, 118.6 ppm silver, 113 ppm arsenic, 111 ppm cobalt and 376 ppm cadmium.

The techniques used to survey stream sediments closely paralleled those used by the Geological Survey of Canada. During 1992, 415 geochemical stream sediment samples were collected from 394 sites. The sample locations were recorded on 1:50 000 scale topographic maps. These samples were analyzed for 40 elements using a combination of Neutron Activation Analysis and Fire Assay/Atomic Absorption. Maps showing sample locations and the concentrations of individual elements are available from the Alberta Geological Survey.

Assays of the stream sediments showed up to 99 parts per billion (ppb) gold, 0.8 ppm silver, 51 ppm copper, 20 ppm lead and 213 ppm zinc. Also, anomalous concentrations were found of antimony, arsenic, barium, cadmium, cobalt, mercury, molybdenum, nickel and uranium. The concentration of some elements in several samples is well above the background level. Some are from sample sites that are down-drainage from known metallic mineral occurrences, but others are from creeks where no metallic mineral occurrences have been documented.

Conclusions

The results of the 1992 survey, combined with previous exploration information pertaining to the study area and neighbouring areas, suggest that good potential exists for the discovery of several types of deposits. They are:

- stratabound copper-lead-zinc-silver deposits of Kupferschiefer and Kipushi type in the Proterozoic rocks of the Clark Range, and possibly, in some Phanerozoic strata;
- MVT lead-zinc deposits in selected carbonate rocks that range from Proterozoic to Triassic age;
- stratiform, sediment-hosted, Sedex-type lead-zinc or nickel-zinc deposits in black shales and other fine-grained clastic rocks, ranging from Proterozoic to, possibly, Paleocene age;
- epithermal or mesothermal precious metal deposits in strata of both Proterozoic and Phanerozoic age;
- paleoplacer magnetite deposits and other heavy minerals, such as gold, in selected horizons within Cretaceous and, possibly, Lower Tertiary units that are derived from the Intermontaine Region of British Columbia;
- diamondiferous kimberlite/lamproite diatremes or placer deposits derived from these rocks; and
- sediment-hosted uranium deposits in clastic rocks that range from Proterozoic to Tertiary in age.

In particular, the Proterozoic clastic or carbonate rocks in the Akamina Syncline of the Clark Range must be considered particularly attractive because more than 70 metallic mineral occurrences are known in these rocks. Elsewhere in the study area, the prospects for finding important metallic mineral deposits are rated as good.

Publications

Dufresne, M.B. and J. Williamson. 1993. The metallic mineral potential of the Southern Alberta Rift. 95th Annual General Meeting and 44th Annual Technical Meeting of the Canadian Institute of Mining, Metallurgy and Petroleum. Calgary, Alberta. May 9–12, 1993.

Williamson, J., M.B. Dufresne and R.A. Olson. 1993. The Southern Alberta Rift in Southwest Alberta: Program to Identify Targets for Metallic Mineral Exploration. Volumes I and II. R.A. Olson Consulting Ltd. 68 pp., appendices, maps.

Reconnaissance Structural-Stratigraphic Study of the Southern Alberta Rift in Southwest Alberta

R.A. Olson Consulting Ltd. (Edmonton), Tri-Ex Consultants Ltd. (London, Ontario), and Discovery Consultants (Vernon, British Columbia)

Project M93-04-034

Some geologists believe that the Southern Alberta Rift is responsible for, or has influenced, metallic mineralizing events in the past. Today, these events are evident in the numerous metallic mineral occurrences that have been found in southern Alberta since the late 1800s. An additional 19 such occurrences were discovered in 1992 in a geological study of the possible targets for metallic mineral exploration in the area. That investigation (see *Geological Mapping, Prospecting and Sampling of the Southern Alberta Rift*) spawned this study, which was carried out in 1993.

The objectives of this study were:

- to search for changes in sedimentary facies, paleocurrent directions and other geological features that would indicate the location and duration of the Southern Alberta Rift; and
- to determine if selected, heavy-mineral fractions in stream drainage sediments provide a better than normal indication of related mineral anomalies.

Two separate activities were undertaken to achieve these objectives. First, selected stratigraphic sections in rock were mapped and examined for their stratigraphic-structural characteristics. These rocks ranged in age from Proterozoic (2.5 billion to 590 million years ago) to Cenozoic (65 million years ago to the present.) Second, orientation heavy-mineral sampling of three selected drainages in the study area were carried out. This involved analysis of specific fractions of the stream sediment using a technique that often shows greater contrasts between background and anomalous values than occur when standard stream silt surveys are carried out.

Background

It is surmised that the Southern Alberta Rift (also called the Vulcan Low) began in Middle Proterozoic time and was intermittently active during the Paleozoic (590 million to 248 million years ago) and Mesozoic (248 million to 65 million years ago) periods. There is some speculation that the rift may have been reactivated as recently as the early Tertiary [illegible] ning 65 million years ago). It is also suspected that the Southern [illegible] mineral deposition is asso[illegible] [illegible] metallic mineral [illegible]

1993 Fieldwork

The stratigraphic-structural investigations were carried [illegible] es were performed and 32 stratigraphic sections were mapped.

The orientation, heavy-mineral study of stream sediments [illegible] 1993. A total of [illegible] ples and 15 spatially [illegible] along three drainages: Grizzly Creek; Pincher Creek; and the Oldman River. Collected samples were subsequently analyzed [illegible]

Results

[illegible] dence of the periods of rift activity. For example, rift-related influences on sedimentation patterns were found in Middle Proterozoic to Cenozoic strata. Also, information was gathered that more precisely indicates the inferred margins of the rift, particularly its southern margin. This evidence came from the Appekunny, Grinnell, Siyeh and Sheppard formations [illegible]

- [illegible]
- the occurrence and nature of cyclic sequences [illegible]
- changes in thickness tre[illegible]

[illegible]

extends northwesterly along the border between Alberta and British Columbia.

Tectonic activity associated with rift structures was less evident from Phanerozoic rocks. Thus, the rift margins during this period of time could not be defined, but subtle hints of rift activity do exist.

Given the evidence for rift activity, particularly when it occurred episodically over a long time, it is likely that several types of mineral deposits are present within or near the Southern Alberta Rift. The most likely deposits of interest are:

- stratiform sediment-hosted lead-zinc and shale-hosted nickel-zinc deposits of the Sedex type. Potential target areas include selected basinal successions in the Middle Proterozoic Purcell Supergroup and the thin, but widespread, euxinic black shale of the Upper Devonian-Lower Mississippian Exshaw Formation.
- stratiform sediment-hosted Kupferschiefer-type copper-silver deposits. The most likely targets are the sandstone-bearing successions of the Appekunny, Grinnell and Siyeh formations, throughout the entire Clark Range.
- carbonate-hosted Mississippi Valley-type lead-zinc deposits. These mineral deposits are most likely to be found in the dolomitized reef and dolostone clast breccia-bearing successions of the Late Devonian Fairholme Group and Palliser Formation.

The orientation, heavy-mineral, stream-sediment survey successfully detected two types of known mineralized zones: clastic sediment-hosted copper-silver types in Proterozoic strata; and carbonate-hosted zinc-lead-silver types in Paleozoic strata. Thus, the technique shows promise for finding similar zones that remain undiscovered. Furthermore, the analysis of heavy mineral concentrates from stream sediments provided a significantly better distinction between background values and anomalous values than is obtained when more conventional stream silt surveys are used. For these particular samples, the difference was an order of magnitude greater than normal.

Conclusions

It was concluded that the area of Alberta above and near the Southern Alberta Rift is geologically complex and is host to many different types of metallic mineral showings. Hence, this area should be regarded as a potentially important source of precious metals and base metals. Furthermore, experience gained with the orientation, heavy-mineral stream-sediment surveying technique shows it has promise for helping to delineate the locations of mineral deposits, and it ought to be used more extensively in this area of the province.

Publication

Olson, R.A., T.R. Iannelli and W.R. Gilmour. 1994. Regional Stratigraphic-Structural Study. Orientation Heavy Mineral Stream Sediment Study. Southern Alberta Rift. Southwest Alberta. Volumes I (101 pp., appendices, maps) and II (20 pp., appendices). R.A. Olson Consulting Ltd.

Mineral Potential, Metamorphism and Petrogenesis of the Crowsnest Volcanics

Geological Survey of Canada (Ottawa) and The University of Calgary (Calgary)

Project C1.21

The Crowsnest Volcanics is a linear north-south zone of extrusive igneous rocks located east and west of Coleman in southwestern Alberta. The zone is Early Cretaceous in age (approximately 100 million years ago) and may host gold, base metals and rare earth elements.

This study was undertaken to determine the volcanological, petrological and mineralogical characteristics of the Crowsnest Volcanics to provide more information on their economic potential.

Methodology

Field studies of selected outcrop areas were carried out, and samples were collected and submitted for geochemical (elemental and isotopic) analysis. Other tests performed on samples included microprobe analysis of mineral phases, standard thin-section petrography, X-ray diffractometry, scanning-electron microscopy and thermodynamic modelling.

Results

Most of the formation comprises fluvially reworked volcaniclastic rocks; lava flows and pyroclastic rocks were rarely preserved.

The volcanic rocks are mildly potassic trachytes and phonolites, with phenocrysts of sanidine, clinopyroxene, titanite, melanite and analcite. Apatite was found to be abundant in some cumulate xenoliths. Whole rock samples do not display geochemical patterns that are consistent with crystal fractionation of alkali or transitional basalt. This and other evidence suggests that the Crowsnest magmas probably originated

by partial melting of moderately metasomatized lithosphere near the crust/mantle boundary 25 to 30 km beneath the surface.

Peak metamorphic conditions were reached before or during Tertiary thrusting.

A tuffaceous pyroclastic unit exposed in a highway roadcut at Iron Ridge contains abundant quantities of sulphides. These sulphides are mainly pyrite, with minor amounts of galena, chalcopyrite and sphalerite. The "juvenile" volcanic fragments in this unit are significantly different from the trachytes and phonolites associated with the Crowsnest Volcanics, and contain abundant biotite and leucite. While these fragments are regarded as the source of modest gold anomalies that were observed previously at Iron Ridge, extensive examination under a scanning electron microscope failed to find gold grains, and a 5-kg sample yielded only 7 parts per billion of gold.

It was concluded that any quantities of gold or base metals hosted by these rocks are not economic.

Publications

Bégin, N.J., E.D. Ghent and R.E. Beiersdorfer. 1995a Mineralogical and geochemical analyses and economic potent[illegible] of the Crowsnest Volcanics. Current Research, Part E. Geological Survey of Canada. Paper 95-1E. pp. 11–2[illegible]

Bégin, N.J., E.D. Ghent and R.E. Beiersdorfer. [illegible] Low-temperature metamorphism of the Crowsnest volc[illegible] suite, southwestern Alberta. Canadian Mineralogist [illegible] review.

Peterson, T.D. and K.L. Currie. 1993. Explosive analcit[illegible] phonolite volcanism, Crowsnest Volcanics. Abstracts. Association of Volcanology and Chemistry of the Earth's Interior Conference. Canberra, Australia. p. 86.

Peterson, T.D. and K.L. Currie. 1993. Analcite-bearing igneous rocks from the Crowsnest Formation, southwester[illegible] Alberta. Current Research, Part B, Geological Survey of Canad[illegible] Paper 93-1B, pp. 51–56.

Peterson, T.D., K.L. Currie, E.D. Ghent, N.J. Bégin [illegible] Beiersdorfer. 1996. Petrology and economic geology of the Crowsnest Volcanics, Alberta. Geological Survey of Canada Bulletin (R.W. Macqueen, editor). In press.

Peterson, T.D., K.L. Currie, E.D. Ghent and R. Beiersdorfer. 1993. Petrology and mineral potential of the volcanic rocks of the Crowsnest Formation. Canadian Institute [illegible] Mining Bulletin. 86:968. p. 69.

Study of the Hydrogeochemistry of Northern Alberta with Specific Reference to the Possible Occurrence of Zn-Pb Deposits

Hitchon Geochemical Services Ltd., Sherwood Park

Project M92-04-003

[illegible]t is believed that if the source were known of the zinc-lead [illegible] ore body at Pine Point, Northwest Territories (NWT[illegible] this knowledge might help geologists find other, similar ore bodies. This relates directly to Alberta since Pine Point is imm[illegible]

[illegible] the ore body's source have been pro[illegible] been accepted as the [illegible]finitive explanation. According to one theory, the ore body is [illegible]ssippi Valley type, involving a mechanism which explains [illegible] deposits.

[illegible] source is geothermal [illegible]brian basement that lies below the [illegible]

[illegible]ion to all Mississippi Valley [illegible]he source of minerals. [illegible]ion water from deep in a sedimentary [illegible]ids ascending from the basement [illegible]on waters of northern [illegible]l content, this would [illegible]he other [illegible]

[illegible]ve of this study was to examine these [illegible]rmine whether they could be related [illegible]

Background

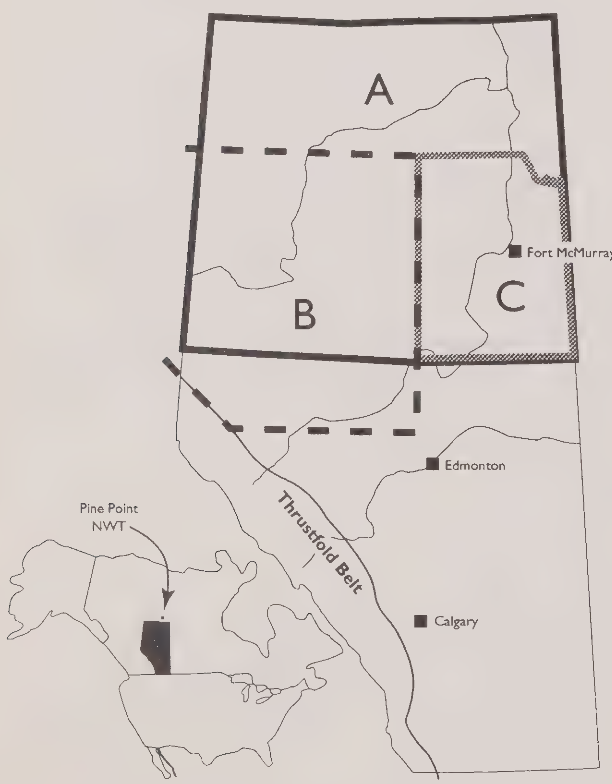
[illegible] Pine Point Zn-Pb deposit comprises sphalerite and [illegible]bound in secondary Middle-[illegible] dolostones. Through geochemical, isotope and fluid-[illegible]hods, it has been concluded that 100–125 million [illegible] Pine Point Group (which is approx-[illegible]380 million years old), the minerals that would become the Pine Point Zn-Pb ore body were deposited in existing [illegible]ite facies. It is also believed these minerals were [illegible]posited from water at 50–100°C. Neither the precise source of the metals nor the exact mode of their transportation in the water has been determined.

It has been calculated that if formation waters are the source of Pine Point zinc, concentrations of zinc that are less than 10 mg/L (and as low as 1 mg/L) could account for the ore body if deposition occurred over 500 000 to five million years at water temperatures of 60–100°C.

However, the concentration of one or both metals in water is not the only consideration. The ratio of one to the other in the source water must also be approximately the same as in the ore body. In the ore, the ratio of lead to zinc ranges from 1:1.7 to 1:2.6 or greater.

Methodology

To obtain information on relevant formation waters, all existing databases for that portion of Alberta between 55°N and 60°N were consulted. This information came from studies carried out previously on behalf of Alberta Research Council and the Energy Resources Conservation Board (now Alberta Energy and Utilities Board). Each agency had performed certain analyses on these samples, and these data, which had not been published previously, were then reviewed and interpreted with respect to this study.



Study area (A) *showing recent hydrogeological evaluations of the Phanerozoic section;* (B) *Peace River Arch (Hitchon, 1990; Hitchon et al., 1990b);* (C) *northeast Alberta (Hitchon, 1991; Bachu et al., 1993).*

Altogether, the unpublished data for 197 samples were deemed to be acceptable for this analysis. These samples fell into three groups: (1) those from Cretaceous aquifers; (2) an intermediate group from Triassic, Permian and Carboniferous aquifers; and (3) those from Devonian aquifers. Their characteristics are described in detail in the project final report. Of greatest importance were the concentrations of five trace elements — lead, zinc, barium, strontium and fluorine — and their distribution over the hydrostratigraphic column.

Results

It was found that the average lead content in formation waters from northern Alberta increases with depth. It ranged from less than 1 mg/L in Cretaceous aquifers to mean values greater than 5 mg/L in pre-Cretaceous aquifers. Also, sharp differences were noted between various types of aquifers. Zinc content showed similar trends, having mean and median values less than 1 mg/L and greater than 3 mg/L in Cretaceous aquifers and Devonian aquifers, respectively.

The results indicated that 75 per cent of the formation waters have lead concentrations that are greater than those for zinc, which is the opposite of their relationship in the ore body. Thus, it was concluded that none of these formation waters could have been responsible for the Pine Point zinc-lead deposit, unless some other explanation could be offered. After detailed consideration of various mechanisms, chemical interactions and mixing that might have been operating at the time of deposition (an exercise that was aided by computer modelling) it was still concluded that the Pine Point ore deposit could not have originated with the formation waters of northern Alberta.

This conclusion raised two questions: (1) are the formation waters of northern Alberta unique with respect to their lead and zinc contents? and (2) if so, what other source is responsible for the Pine Point ore body?

A literature search revealed that formation-water data were available for several basins that hosted Mississippi-type deposits of lead and zinc. Examination of these data showed that the northern Alberta case was the only one in which lead contents exceeded those of zinc. This seems to suggest that northern Alberta formation waters are unique in this regard.

Lead and zinc data were also available for two cases where the brines responsible for ore deposits had geothermal origins. Here, the zinc concentration exceeded the lead concentration. This is consistent with the ratio of the two metals in the Pine

Point ore. Since lead and zinc contents have not been determined on samples taken from geothermal hot springs in western Canada, some indirect evidence was sought.

Because the temperature of the fluid is regarded as a factor contributing to deposition, the search focused on the Great Slave Lake Shear Zone. It was found that hot fluids had risen through this feature over various time periods, and they could be the source of the Pine Point ore deposit. It is suspected that at some point the geothermal fluids met saline formation waters containing hydrogen sulphide, and the place where they met became the site of the Pine Point ore deposit.

This concept radically changes the approach to be used in any exploration program that aims to find other zinc-lead deposits. Had formation waters been responsible, the exploration strategy would involve:

- determining the present regional geochemical characteristics of the formation waters;
- evaluating the present hydrogeological and geothermal regimes; and
- extrapolating these geochemical, geothermal and hydrogeological aspects back to the time of deposition to determine the approximate location of other deposits.

On the other hand, if geothermal fluids are responsible, the strategy would involve:

- locating suitable shear zones and faults which geothermal fluids might have ascended; and
- determining the location of appropriate brines or saline formation waters containing hydrogen sulphide.

When the latter strategy was used to evaluate known geological information about Alberta, some important observations were noted. It was observed that the distribution of known lead and zinc occurrences in Alberta, which otherwise seems to be random, can be related to three major crustal discontinuities: the Great Slave Lake Shear Zone; the Snowbird Tectonic Zone (and associated Thorsby Low); and the Vulcan Low (Southern Alberta Rift). At least half Alberta's lead and zinc occurrences were found to be associated with these three features.

Conclusion

It was concluded that if the Pine Point ore deposit is the result of geothermal fluids ascending along the Great Slave Lake Shear Zone and meeting brines in the lowermost Phanerozoic strata, there is no reason why similar deposits should not be found elsewhere along the same shear zone in the Canadian Shield. The brines are present; all that is needed are appropriate host aquifers.

Publications

Hitchon, B. 1993a. Geochemistry of Formation Waters, Northern Alberta, Canada: Their Relation to the Pine Point Ore Deposit. Hitchon Geochemical Services Ltd. 99 pp.

Hitchon, B. 1993b. Geochemistry of formation waters, northern Alberta: preliminary results. Geological Association of Canada/Mineralogical Association of Canada Joint Annual Meeting. Edmonton, Alberta. May 17–19, 1993.

Analysis of Paleozoic Core Data for the Evaluation of Potential Pb-Zn Deposits in Northeast Alberta

Don McPhee, Calgary

Project M93-04-032

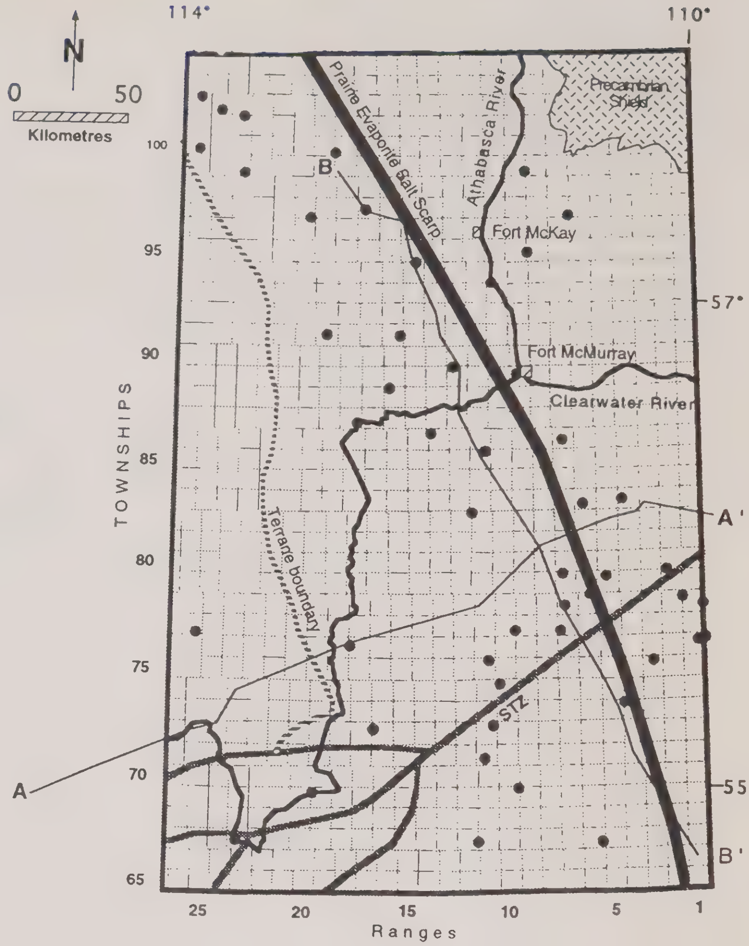
The lead-zinc deposit at Pine Point, Northwest Territories (NWT) is regarded as Canada's best known example of a Mississippi Valley-type ore body. Considering that Pine Point is located near the northern border of Alberta, geologists suspect that a similar deposit may exist in northeastern Alberta. The objective of this project was to examine specific sections of existing drill cores taken from that area of Alberta to ascertain whether there is any evidence of such a deposit.

Background

The general characteristics of Mississippi Valley-type ore deposits are widely known among geologists. They are:

- the ores have a simple mineralogy — they comprise galena and sphalerite, plus minor amounts of pyrite, marcasite, chalcopyrite, barite and fluorite;
- ores are stratiform and epigenetic (deposited later than the host rock);
- most deposits are hosted by carbonates, and these carbonates are dolostones, brecciated with karsting, unmetamorphosed and Proterozoic to Cretaceous in age;
- there is no evidence of associated igneous activity;
- ores are located near the edges of basins, or along arches or "hinge zones" between basins;
- ores are precipitated from brines that were 5–10 times more saline than normal sea water, and ranged in temperature from 80°C to 200°C; and
- sulphur isotopes indicate coeval sea water sulphate, whereas lead isotopes are ambiguous and can be either anomalous (shallow crustal) or normal (deep crustal).

It has been suggested that the Pine Point deposit is associated with the Great Slave Lake Shear Zone, which angles across northwestern Alberta and passes beneath Pine Point. The age of the deposit, however, is not certain. Some indications suggest that activities causing deposition of lead and zinc began in the Late Jurassic to Early Cretaceous (approximately 150–100 million years ago) and ended in the Late Cretaceous to Paleocene (84–58 million years ago). Determinations from lead isotopes suggest late Devonian (361 ± 13 million years ago) to late Pennsylvanian (290 million years ago), and there is further evidence that Pine Point mineralization occurred at the same time as magnesite and talc mineralization occurred within Cambrian carbonates in the southern Rocky Mountains. This points to Late Devonian to Early Mississippian (360–320 million years ago).



Map of study area showing well locations relative to the Prairie Evaporite salt dissolution scarp and the Snow Bird Tectonic Zone (STZ).

Methodology

The study area was that portion of northeastern Alberta bounded by the Saskatchewan border to the east, the Primrose Air Weapons Range to the south, the NWT border to the north, and the Fifth Meridian to the west. Within this area, cores from 50 wells were chosen for examination, and cores from 11 wells outside the area in northwest Alberta were also studied. These cores are stored at the Energy Resources Conservation Board (now Alberta Energy and Utilities Board, EUB) Core Research Centre in Calgary.

Permission was granted by the EUB to remove 100–200 gram samples from each core. This resulted in 675 samples, which were analyzed for 30 elements by Inductively Coupled Plasma Spectrophotometry. Some of these samples (247) were also analyzed for gold by Fire Assay-Atomic Absorption Emission Spectrometry.

Portions of cores that were analyzed were chosen on the basis that mineralizing fluids responsible for a lead-zinc deposit might have been channeled to overlying Paleozoic strata by either the Great Slave Lake Shear Zone (outside the study area) or the Snowbird Tectonic Zone. The latter, which lies within the study area, is considered to be remarkably similar to the Great Slave Lake Shear Zone. Emphasis was placed on the major carbonate formations, which included the Winnipegosis (Keg River) Formation, the Beaverhill Lake (Waterways) Formation, as well as the Cooking Lake and Grosmont formations of the Woodbend Group.

Results

No significant evidence of lead-zinc mineralization was found. Some interesting anomalies were observed that merit further examination. The well locations of these anomalies are given in the project final report.

The final report also contains a detailed summary of the geology of the Western Canada Sedimentary Basin, plus all well locations, core characteristics and sample analyses.

Publication

Turner, A. and D. McPhee. 1994. Analysis of Paleozoic Core Data for the Evaluation of Potential Pb-Zn Mineralization in Northeastern Alberta. 51 pp., appendices.

Tectonic Evolution of the Precambrian Shield of Northeastern Alberta

Geological Survey of Canada, Calgary

Project C1.11

The northeastern area of Alberta is regarded as a likely location for discovering minerals, primarily because it is part of the Canadian Shield, a geological feature that hosts many economic mineral deposits in other provinces. Furthermore, recent geological investigations in Saskatchewan, Northwest Territories and other nearby areas of Alberta strongly suggest that an understanding of this area is essential for comprehending the Early Proterozoic and older tectonic evolution of the Shield.

This project was one of several carried out in this area of Alberta by the Geological Survey of Canada. The specific goals of the project were to determine:

- the geometry, origin and movement patterns of shear zone deformation;
- the relative timing of shear zone activity;
- the relative chronologies of plutonism and deform[illegible] and
- the identity of any new zones of mineralization/ alteratio[illegible]

The project included laboratory studies to:

- provide the absolute ages for plutonic and basement [illegible]es;
- conduct metallogenic studies to establish relationships between mineralization and deformation;
- acquire geochemical data for granite petrogenesis;
- conduct electron microprobe studies of mineral [illegible] to establish the pressure and temperature conditions [illegible] metamorphism;
- analyze the movement patterns of shear zones; and
- integrate studies of remotely sensed data.

In particular, it is believed that establishing the geome[illegible] and movement patterns of the main shear zones in the area [illegible] well as their timing and grade of deformation, will help asce[illegible]tain the potential for finding shear zone-hosted gold deposit[illegible]

Results

A previously unreported shear zone was found at Andr[illegible] Lake. It is interpreted as a dextral, oblique, ductile thrust [illegible] that placed the basement of the Taltson arc on to plutons that probably intruded the Archean Churchill craton to the east.

Geological field mapping of the Charles Lake and Lela[illegible] Lakes shear zones and adjacent plutonic bodies indicates that the shear zones were ductilely deformed at granulite grade by a complex interplay of sinistral and dextral shear motion. This affected the basement of the Taltson Magmatic Zone and the plutonic rocks. This shearing is believed to have occurred earlier than 1 932 million [illegible]

Isotope studies using $^{40}Ar/^{39}Ar$ were carried out on hornblende, biotite and muscovite. They indicate that shear-zone deformation of younger amphibolite to greenschist occurred between 1 900 and 1 800 million years ago. Furthermore, a combination of the argon isotope studies and structural studies indicates that sulphide mineralization was either introduced or highly remobilized during greenschist grade deformation.

[illegible] indicates that the gneisse[illegible] [illegible] range from 3 200 to 2 [illegible] [illegible] demonstrates that certain parts of the [illegible] Magmatic Zone are Archean and likely prospects for diamond [illegible]

[illegible] the plutonic [illegible] range in age from [illegible]sional granitoids. Post-col[illegible] 1 918 million years [illegible]limentation in the Waugh [illegible] million years ago.

[illegible] gneisses scattered [illegible] were found to be [illegible]

[illegible] that some isotopic techniq[illegible] new mineral [illegible] In addition, some [illegible] are worth consi[illegible]

[illegible] being prepared [illegible]

Publications/Presentations

[illegible] McNicoll. 1993 [illegible] of the Taltson [illegible] Alberta. Cur[illegible]

[illegible]

Grover, T.W., D.R.M. Pattison and M.R. McDonough. 1994. Granulite to greenschist facies shear zone evolution, northeastern Alberta. Geological Society of America. Abstracts with Programs. 26:7. pp. A–49, A–50.

McDonough, M.R. 1996. Structural controls and age constraints on sulphide mineralization, southern Taltson Magmatic Zone, northeastern Alberta. Geological Survey of Canada Bulletin (R.W. Macqueen, editor). In press.

McDonough, M.R. 1995. Structural controls and age constraints on sulphide mineralization, southern Taltson Magmatic Zone, northeastern Alberta (Poster Session). Program and Abstracts. Fourth Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. April 6–7, 1995. Calgary, Alberta.

McDonough, M.R. and H.J. Abercrombie. 1995. Mineral occurrences in Middle Devonian carbonates, Salt River and Stony Islands (Slave River) areas, northeast Alberta. Current Research 1995-B. Geological Survey of Canada. pp. 125–130.

McDonough, M.R. and V.J. McNicoll. 1995. The Waugh Lake Basin: a 2.01-1.971 Ga back arc basin, southern Taltson Magmatic Zone, northeastern Alberta (Poster Session). Program and Abstracts. Fourth Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. April 6–7, 1995. Calgary, Alberta.

McDonough, M.R., M.A. Cooley and E.M. Schetselaar. 1994. Geology, Hay Camp, Alberta (74M/11). Geological Survey of Canada. Open File Report 2832. 1:50 000 scale geological map.

McDonough, M.R., T.W. Grover and V.J. McNicoll. 1993a. Geology and magnetic zone signature of the southern Taltson Magmatic Zone, northeastern Alberta (NTS 74M). Program and Abstracts. The Calgary Mining Forum. Calgary Mineral Exploration Group Society. March 3–4, 1993. p. 16. *Also*: Canadian Institute of Mining Bulletin, 86:968. p. 57.

McDonough, M.R., T.W. Grover and V.J. McNicoll. 1993b. New geological maps of the Shield of northeastern Alberta. Canadian Institute of Mining Bulletin, 86:968, p. 69.

McDonough, M.R., T.W. Grover and V.J. McNicoll. 1993c. New insights on the geology of the Early Proterozoic southern Taltson Magmatic Zone, northeastern Alberta. Program and Abstracts. Geological Association of Canada/Mineralogical Association of Canada Joint Annual Meeting. May 17–19, 1993. Edmonton, Alberta. p. A–68.

McDonough, M.R., T.W. Grover and V.J. McNicoll. 1993d. Geology and mineral potential of the Early Proterozoic southern Taltson Magmatic Zone, northeastern Alberta. 95th Annual General Meeting and 44th Annual Technical Meeting of the Canadian Institute of Mining, Metallurgy and Petroleum. May 9–12, 1993. Calgary, Alberta.

McDonough, M.R., T.W. Grover and V.J. McNicoll. 1993e. Geological evolution and magnetic signature of the southern Taltson Magmatic Zone, northeastern Alberta (NTS 74M). Report of LITHOPROBE Alberta Basement Transects Workshop. LITHOPROBE Report #31. pp. 130–133.

McDonough, M.R., T.W. Grover, V.J. McNicoll, M.A. Cooley, E.M. Schetselaar and N.N. Robinson. 1994. Geology, Cornwall Lake, Alberta (74M/10). Geological Survey of Canada. Open File Report 2896. 1:50 000 scale geological map.

McDonough, M.R., T.W. Grover, V.J. McNicoll, M.A. Cooley, E.M. Schetselaar, N.N. Robinson and J. Bednarski. 1995. Geology, Colin Lake, Alberta-Saskatchewan (74M/9). Geological Survey of Canada. Open File 3047. 1:50 000 scale geological map.

McDonough, M.R., T.W. Grover, V.J. McNicoll and D.D. Lindsay. 1993. Preliminary report of the geology of the southern Taltson Magmatic Zone, northeastern Alberta (74M/14, 74M/15 and 74M/16). Current Research, Part C, Geological Survey of Canada. Paper 93-1C, pp. 221–232.

McDonough, M.R., T.W. Grover, V.J. McNicoll, D.D. Lindsay, K.L. Kelly and P.G. Guerstein. 1994a. Revised Geology, Mercredi Lake (74M/15), Alberta-Northwest Territories. Geological Survey of Canada. Open File Report 2904. 1:50 000 scale geological map.

McDonough, M.R., T.W. Grover, V.J. McNicoll, D.D. Lindsay, K.L. Kelly and P.G. Guerstein. 1994b. Revised Geology, Andrew Lake, Alberta (74M/16), Alberta-Saskatchewan-Northwest Territories. Geological Survey of Canada. Open File Report 2905. 1:50 000 scale geological map.

McDonough, M.R., T.W. Grover, V.J. McNicoll, D.D. Lindsay, K.L. Kelly and P.G. Guerstein. 1994c. Geology, Tulip Lake, Alberta (East half, 74M/14), Alberta-Northwest Territories. Geological Survey of Canada. Open File Report 2820. 1:50 000 geological scale.

McDonough, M.R., T.W. Grover, V.J. McNicoll, D.D. Lindsay, K.L. Kelly and P.G. Guerstein. 1993a. Geology, Mercredi Lake, Alberta (74M/15). Geological Survey of Canada. Open File Report 2629. 1:50 000 scale geological map.

McDonough, M.R., T.W. Grover, V.J. McNicoll, D.D. Lindsay, K.L. Kelly and P.G. Guerstein. 1993b. Geology, Andrew Lake, Alberta (74M/16). Geological Survey of Canada. Open File Report 2664. 1:50 000 scale geological map.

McDonough, M.R., T.W. Grover and V.J. McNicoll. 1994. New geological maps of the Canadian Shield of northeastern Alberta. Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Annual General Meeting. May 2–4, 1994. Toronto, Ontario.

McDonough, M.R., V.J. McNicoll and T.W. Grover. 1994. Whole rock major and trace element analyses of selected mineral occurrences, Taltson Magmatic Zone, Canadian Shield, northeastern Alberta (NTS 74M and 74L). Geological Survey of Canada. Open File Report 2893. 6 pp.

McDonough, M.R., V.J. McNicoll, T.W. Grover and H.E. Plint. 1994. Geochronological and kinematic constraints on shear zone evolution, southern Taltson Magmatic Zone, Canadian Shield, northeastern Alberta. Geological Society of America. Abstracts with Programs. 26:7. p. A–135.

McDonough, M.R., V.J. McNicoll and E.M. Schetselaar. 1995. Age and kinematics of crustal shortening and escape in a two-sided oblique-slip collisional and magmatic orogen, Paleoproterozoic Taltson Magmatic Zone, northeastern Alberta. *In:* Ross, G.M (ed), LITHOPROBE Alberta Basement Transects Workshop. LITHOPROBE Report #47. pp. 264–308.

McDonough, M.R., V.J. McNicoll and R.J. Thériault. 1995a. Taltson basement complex: basement to a Paleoproterozoic continental collisional and magmatic orogen. (Poster Session). Program and Abstracts. Fourth Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society April 6–7, 1995. Calgary, Alberta.

McDonough, M.R., V.J. McNicoll and R.J. Thériault. 1995b. Taltson basement complex: basement to a Paleoproterozoic continental collisional and magmatic orogen. Program with Abstract Geological Association of Canada. Vol. 20. p. A68.

McDonough, M.R., H.E. Plint, V.J. McNicoll and T.W. Grover. 1994. $^{40}Ar/^{39}Ar$ and K-Ar age constraints on shear zone evolution, southern Taltson Magmatic Zone, northeastern Alb *In:* Ross, G.M (ed), LITHOPROBE Alberta Basement Tran Workshop (Feb 14,15). LITHOPROBE Report #37. LITHO PROBE Secretariat. University of British Columbia. pp. 2

McNicoll, V.J. and M.R. McDonough. 1995. The Waug Lake Basin: a 2.01-1.971 Ga back arc basin, southern Taltson Magmatic Zone, northeastern Alberta. *In:* Ross, G.M (ed LITHOPROBE Alberta Basement Transects Workshop. LITHOPROBE Report #47. pp. 309–328.

McNicoll, V.J., M.R. McDonough and T.W. Grover. U-Pb geochronological studies in the southern Taltson Magmatic Zone, northeastern Alberta. *In:* Ross, G.M. (ed LITHOPROBE Alberta Basement Transects Workshop (14–15). LITHOPROBE Report #37. LITHOPROBE Secretariat. University of British Columbia. pp. 270–27

McNicoll, V.J., M.R. McDonough and T.W. Grover. 1993. Preliminary U-Pb geochemistry of the southern Taltson Magmatic Zone, northeastern Alberta (NTS 74M). Report of LITHOPROBE Alberta Basement Transects Workshop. LITHOPROBE Report #31. p. 129.

Plint, H.E. and M.R. McDonough. 1994. $^{40}Ar/^{39}Ar$ and K-Ar age constraints on shear zone evolution, southern Taltson Magmatic Zone, northeastern Alberta. Canadian Journal of Earth Sciences

Schetselaar, E.M. and M.R. McDonough. 1995a. Shear zone mapping using ERS-1 SAR imagery, Paleoproterozoic Taltson Magmatic Zone, Canadian Shield, northeastern Alberta. ITC Journal (The Netherlands). In press

Schetselaar, E.M. and M.R. McDonough. 1995b. Integration of ERS-1 SAR and total field aeromagnetic images for the spatial and kinematic characterization of the Charles Lake shear zone, Canadian Shield, northeastern Alberta: a mathematical morphologic approach. Conference Proceedings. Geomatics 95. Ottawa, Ontari

Analysis and Cataloguing of Precambrian Shield Rock Samples in Support of Government and Industry Mapping and Exploration Programs

Alberta Geological Survey, Edmonton

Geological Survey (AGS) posed Precambrian Shield d in 11 detailed geological d 11 610 rock samples, and 1 135 rock collection is not sorted not readily availabl

ject were

ples in a database;

- to publish maps of the sample locations; and
- to keep the database current by entering new samples as

maps showing the orig- e collection were prepared for Lake North and Ashton Lake, and is compiled for Bayonet Lake. The data extracted from the original field ligited maps were prepared and ns were added. The three completed

For example, the Andrew Lake South map shows 984 collection sites. Modal and chemical analyses were performed on 24 samples in 1963, and only these sample locations are shown on the map. The distribution of rock types for this mapped area are approximately one-third metasedimentary, one-quarter each granite and gneiss, and the remainder were basic rocks, amphibolite and granite pegmatite.

Although the project did not continue beyond the original three maps, the rock collection has been used to supply samples for other geological investigations supported by the MDA program. Also, anomalous analyses have resulted in some staking activity in the region.

Persons wishing to have access to the rock collection, which is stored at the Mineral Core Research Facility in Edmonton, may do so by appointment only. Maps are also available.

Publications

Edwards, W.A.D., D.R. Boisvert and S.A. Miller. 1993a. Andrew Lake North. Precambrian Shield Rock Sample Location Map (part of 74M/16). Map 219. Alberta Research Council.

Edwards, W.A.D., D.R. Boisvert and S.A. Miller. 1993b. Ashton Lake. Precambrian Shield Rock Sample Location Map (part of 74M/16). Map 220. Alberta Research Council.

Edwards, W.A.D., D.R. Boisvert, S.A. Miller and D.K. Chao. 1993. Andrew Lake South. Precambrian Shield Rock Sample Location Map (part of 74M/16). Map 218. Alberta Research Council.

Edwards, W.A.D., S.A. Miller and D.R. Boisvert. 1993. Precambrian Shield of Alberta Rock Sample Collection. Alberta Research Council. Open File Report 1993-20. 23 pp., appendices.

Evaluation of Mineralization Potential of Selected Areas of Northeastern Alberta

Alberta Geological Survey, Edmonton

Project M92-04-007

Previous mapping of certain areas of the Canadian Shield in northeastern Alberta indicated some promising areas for gold and other mineral deposits. The purpose of this project was to investigate these areas in more detail. Specifically, the objectives were:

- to evaluate the mineral potential of the exposed Shield of northeastern Alberta;
- to enhance all mineral exploration through an improved understanding of the region's geology;
- to investigate relationships between shear zones and mineral occurrences;
- to determine the depositional environments of the Waugh Lake Group; and
- to prepare maps showing mineral occurrences that can be used in land-use planning.

Background

The study area was mapped from 1955 to 1985, but the area was not extensively explored for economic minerals. Nonetheless, more than 200 mineral showings were identified during this earlier mapping, but follow-up by exploration companies has been limited. Of particular interest in the current project were fault zones and metasedimentary rocks, since they are often associated with mineralization.

Methodology

Samples were collected from natural outcrops or old exploration trenches and then analyzed for their elements by Inductively Coupled Plasma spectrophotometry. Fire Assay and Atomic Absorption Emission spectrometry were used to determine the content of gold and other minerals. All data were then entered into a database so that geological maps could be produced.

For purposes of reporting the data, distinctions were made among mineral occurrences, mineral showings and mineral prospects. A "showing" was defined as an occurrence of some merit that has not yet become a prospect, and a "prospect" is defined as a non-producing mining property that is under development.

Thus, a mineral occurrence was elevated in this project to a showing if it met at least one of the following criteria:

- the occurrence contains significant (economical to sub-economical) concentrations of base or precious metals or radioactive substances; or
- the occurrence shows a radioactivity level above a threshold of 2 000 counts per second (total count channel).

Also, similar showings in a relatively small area were grouped together as one showing. Showings were considered to be similar when they indicated a similar geological and structural setting, or indicated identical mineral association (paragenesis).

Results

A total of 150 mineral occurrences were noted. Some of these were reported previously and some are new. Considering the way showings were defined, 19 mineral occurrences were classified as showings. This means their mineral content is likely economic.

The best metallic mineral showings in the sedimentary and volcanic rocks of the Waugh Lake Group have up to 3.2 parts per million (ppm) gold.

Several showings in gossanous high-grade metasediments near Pythagoras Lake contain arsenopyrite and gold contents up to 600 parts per billion (ppb). Another interesting showing is a highly radioactive molybdenite occurrence (0.29 per cent U_3O_8 and 0.25 per cent MoS_2) near the west arm of Andrew Lake. It might be related to the shear zone through Mylonite Lake. A sulphide showing having approximately 15 per cent pyrrhotite and 0.03 per cent copper is located near Selwyn Lake. The sulphides consist of pyrite, pyrrhotite and chalcopyrite and are found exposed over a distance of more than 1 000 m, and are related to the Charles Lake shear zone.

Nine uranium showings were identified. Most are hosted in pegmatite and related granitoids. Their average grades are subeconomic, however.

Two showings were located in the Leland Lakes area. A Myers Lake gold showing indicated 200 ppb gold, and a Myers Lake radioactive showing had a radiation level of up to 2 000 total counts per second.

Conclusions

Potential for gold and base metals exists in the study area These deposits may be associated with metasedimentary belts in shear zones and numerous late-phase quartz-tourmaline veins in the Waugh Lake Group. While the identified showings of uranium were disappointing, they could be associated with rare earth elements in appreciable quantities.

Publications

Langenberg, C.W. and D.R. Eccles. 1996. Metallic mineral occurrences of the exposed Canadian Shield of northeastern Alberta. Alberta Geological Survey Bulletin 64. In prep.

Langenberg, C.W., T.R. Ianelli and D.R. Eccles. 1996. Revised geology and mineral occurrences of the Aphebian Waugh Lake Group, northeastern Alberta. Alberta Geological Survey. Open File Report 1995-5. In press.

Langenberg, C.W., H.P. Salat and D.R. Eccles. 1995. Mineral occurrences of the Selwyn and Leland lakes areas. Alberta Geological Survey. Open File Report 1994-05. 26 pp.

Langenberg, C.W., H.P. Salat, A. Turner and D.R. Eccles. 1993. Evaluation of the economic mineral potential in the Andrew Lake-Charles Lake area of northeast Alberta. Alberta Geological Survey. Open File Report 1993-08. 73 pp.; one map.

Salat, H.P., D.R. Eccles and C.W. Langenberg. 1994. Geology and mineral occurrences of the Aphebian Waugh Lake Group. Alberta Geological Survey. Open File Report 1994-04. 36 pp.

Metallogenic Studies of U-polymetallic Mineralization of the Athabasca Basin and Adjacent Area

Geological Survey of Canada, Ottawa

Project C1.12

Considering the analogous geological conditions that exist in the northwestern Saskatchewan and northeastern Alberta portions of the Athabasca Basin, and the uranium and mineral dis- [illegible] this pro- [illegible] was undertaken to delineate areas of likely metallogenic mineralization in the Alberta part of the basin.

Given this broad goal, the project had the following objec- [illegible]

- investigate and sample the available drill core and mineral occurrences, and conduct chemical and isotopic analyses of the collected materials to allow interpretation of the metallogenic features;
- make comparisons between the Saskatchewan and Alberta portio[illegible]f the basin to identify similarities and differences in mineralization processes; and
- develop exploration criteria and recommend additional [illegible] to enhance the efficiency of mineral exploration.

The investigation was carried out in cooperation with the Alberta Geological Survey.

Methodolo[illegible]

Some of the material studied in this project came from drill core stored at the Alberta Geological Survey, and it was supplemented by sampling of outcrops in selected areas of northern Alberta. For comparison purposes, samples were collected from drillholes in the Key Lake and Cigar Lake deposits of Saskatchewan. Various laboratory studies and analyses were conducted by the Geological Survey of Canada in Ottawa and the Saskatchewan Research Council in Saskatoon.

Results

Basement and overlying rocks in the Alberta portion of the Athabasca Basin indicate favourable conditions for uranium-polymetallic deposits. The metallogenic features of the Alberta portion are compatible with a genetic model established for world-class unconformity deposits, particularly those from the Saskatchewan part of the basin.

The basement rocks in Alberta include Archean and Aphebian granitoid and Aphebian metasedimentary types with layers of pyritic, graphitic metapelites. Typically, regolith is present at the top of the basement rocks. Elevated values of uranium are associated with granitic rocks, particularly with alkali feldspar-rich granitoids, Fishing Creek granitoids, and grey foliated granitoids, as well as with felsic mylonite, chloritized graphitic-pyritic metapelite and altered pegmatoids. Nickel mineralization is locally associated with chloritized biotite gneiss.

It was found that Athabasca Group rocks in the Alberta portion of the basin contain polymetallic mineralization of uranium, nickel, arsenic, cobalt, molybdenum and zinc. Elevated values of chromium were found in rocks from the study area.

Distribution of these assemblages in Alberta is structurally controlled by the sub-Athabasca unconformity. The lithostratigraphic distribution of indicator elements, such as uranium, nickel, cobalt, arsenic and molybdenum, is similar to that in the Saskatchewan portion of the basin.

These results confirm the possibility that unconformity-type, economic deposits do exist in northeastern Alberta.

Publications/Presentations

Ruzicka, V. 1996. Metallogenic features of uranium-polymetallic mineralization, Athabasca Basin, Alberta; and comparison with other parts of the basin. Geological Survey of Canada Bulletin (R.W. Macqueen, editor). In press.

Ruzicka, V. 1994a. Models for world class uranium/polymetallic unconformity deposits, Canada and Australia. Geological Survey of Canada. Minerals Colloquium, Program with Abstracts. January 17–19, 1994. Ottawa, Ontario. p. 2.

Ruzicka, V. 1994c. Metallogenic features of the Athabasca Basin, Alberta. Program and Abstracts. Third Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. February 10–11, 1994. Calgary, Alberta. pp. 31 and 45.

Ruzicka, V. 1994d. Metallogenic features of the Athabasca Basin, Alberta. Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Annual General Meeting. May 2–4, 1994. Toronto, Ontario.

Ruzicka, V. 1993a. Potential for uranium-polymetallic deposits in the Athabasca Basin, NE Alberta. Program and Abstracts. The Calgary Mining Forum. Calgary Mineral Exploration Group Society. March 3–4, 1993. Calgary, Alberta. p. 33.

Ruzicka, V. 1993b. Models for Canadian unconformity deposits: an important component in metallogenic studies, exploration and mineral resource appraisals. International Atomic Energy Agency Technical Committee Meeting on Recent Developments in Uranium Resources and Supply. Preprint T2-TC 394.13. May 24–28. Vienna, Austria. 34 pp.

Ruzicka, V. 1993c. Potential for uranium-polymetallic mineralization in the Athabasca Basin, Alberta. Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Annual General Meeting. May 9–12, 1993. Calgary, Alberta. p. 68.

Ruzicka, V. 1993d. Comparative studies of metallogenic features of the Alberta portion of the Athabasca Basin with the Saskatchewan part of the basin. Current Research, Part D. Geological Survey of Canada. Paper 93-1E. pp. 175–184.

The Mineral Deposits Potential of the Marguerite River Area

Alberta Geological Survey (Edmonton) and Apex Geoscience Ltd. (Edmonton)

Project M93-04-038

Little is known about the geology of that portion of northeastern Alberta represented by NTS map 74E (Bitumount), which encompasses Fort MacKay and the Marguerite River area. With the exception of some uranium exploration, the general absence of exposed bedrock has discouraged much geological investigation in the past. Nonetheless, the area is situated on the edge of the Western Canada Sedimentary Basin, it is underlain by Precambrian Shield rocks and it is discharging large volumes of brines from the subsurface. Therefore, it should be a promising area for mineralization.

For these reasons, the Alberta Geological Survey conducted an assessment of the potential for metallic mineral deposits in the Precambrian, Devonian and Cretaceous rocks in the Fort Mackay and Marguerite River regions of the Bitumount map area.

Methodology

Field exploration included prospecting and collecting rock samples, as well as obtaining till and fluvial sediment samples. Tests for radioactivity were carried out in the field and on cores

removed previously from the area. Laboratory analyses and petrographic studies were carried out, and information from existing coal databases was examined.

Results

Based on magnetic data, the map area can be divided into two segments. One, in the eastern half of the area, has a low magnetic background. It represents the Archean Rae Subprovince. The other, western segment has a strong magnetic background. It is considered to be part of the Proterozoic Taltson Arc, a north-south trending magmatic belt.

The Precambrian rocks underlying the area comprise porphyroblastic granitoids, granitoids and gneisses that are weakly to strongly foliated. Also present is mafic meta-igneous rock of unknown origin and strongly mylonized (milled or ground) rocks. The latter are particularly dominant in the southern portion of the Marguerite River area.

Devonian rocks rest unconformably on the Precambrian basement. These rocks comprise basal sandstone, conglomerate, shale, siltstone, dolomite, salts and anhydrite.

Cretaceous and Devonian rocks are separated by an unconformity that is the result of subaerial erosion and periodic salt dissolution karsting. Shales from various sources dominate, but these rocks also comprise sandstone, oil-impregnated quartz sands and siltstone.

The Quaternary and Recent sediments are primarily till and glaciofluvial outwash deposits.

Several new sulphide and radioactive occurrences were discovered in the Marguerite River area. A mylonite zone, found to be 2–4 km in width, yielded samples having elevated concentrations of copper, zinc, cobalt, nickel, chromium and vanadium. Also, anomalous concentrations of uranium, thorium, cerium, lanthanum, and neodymium were found, along with elevated concentrations of lead, bismuth and molybdenum.

A spring water discharge from carbonate rocks near Fort MacKay yielded anomalous concentrations of silver, lead, arsenic, chromium, antimony, vanadium, boron, bromine and strontium.

Coal exploration drill cores taken near the Firebag River contain anomalous concentrations of gold (up to 1.04 grams per tonne) in oil-stained or impregnated, Early Cretaceous coal, shale and sandstones.

Till and fluvial sediments from the Firebag River area showed anomalous assays for gold, silver, arsenic, zinc, copper, bromine and fluorine.

Some positive indications for diamonds were also found. Analysis showed that the [illegible] found in the area was consistent with that of garnets that are associated with diamonds.

Overall, the exploration data suggest that favourable conditions exist in the area for several base- and precious-metal deposits. These prospects include:

- brine or hydrothermal gold deposits;
- Archean shear zone-hosted gold deposits;
- Mississippi Valley-type lead-zinc deposits;
- sediment-hosted base-metal deposits (lead, zinc, copper, nickel, silver, gold);
- granitoid-related uranium, rare-earth element, precious metal or base-metal deposits;
- unconformity-related, sandstone-hosted or vein-type uranium deposits;
- diamondiferous kimberlite or lamproite diatremes; and
- various types of placer or paleoplacer deposits (gold, diamonds, titanium).

Publications/Presentations

Dufresne, M.B., M.M. Fenton, J.G. Pawlowicz and R.J.H. [illegible] 1994a. Economic mineral potential of the Marguerite River and Fort MacKay areas, northeast Alberta (NTS 74E): preliminary studies. Third Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. February 10-11, 1994. Calgary, Alberta.

Dufresne, M.B., M.M. Fenton, J.G. Pawlowicz and R.J.H. Richardson. 1994b. Economic mineral potential of the Marguerite River and Fort MacKay areas, northeast Alberta (NTS 74E): preliminary studies. Poster Presentation. [illegible]adian Institute of Mining, Metallurgy and Petroleum (CIM) Annual General Meeting. May 2–4, 1994. Toronto, Ontario.

[illegible] Fenton, J.G. Pawlowicz and R.J.H. Richardson. 1994c. Economic mineral potential of the [illegible]rite River and Fort MacKay areas, northeast Alberta (NTS 74E): preliminary studies. Poster Presentation. Canadian Institute of Mining and Metallurgy. May 1994. Calgary, [illegible]

Dufresne, M.B., B.A. Henderson, M.M. Fenton, J.G. [illegible] and R.J.H. Richardson. 1994. The economic mineral deposits potential of the Marguerite River and Fort MacKay areas, northeast Alberta. Alberta Research Council. Open File Report 1994-09. 67 pp., appendices.

Quaternary Geology and Till Geochemistry

Geological Survey of Canada, Calgary

Project C1.13

While no known deposits of significant minerals have been found in northeastern Alberta, the close proximity of the area to major deposits in Saskatchewan and Northwest Territories continues to drive exploration efforts. With the Pine Point Zn-Pb deposit 200 km north, and the Cluff Lake and Uranium City uranium deposits only 150 km and 100 km, respectively, to the east in Saskatchewan, various techniques are being tried to discover similar deposits in Alberta. One potentially useful approach in this regard is to use till geochemistry, which has become increasingly accepted when working in flat and rolling terrain.

Previous work has shown that till geochemistry can determine ice flow patterns and identify till sheets associated with each pattern. In turn, this can point to the source area of minerals transported by ice action.

In a project carried out in cooperation with the Alberta Geological Survey over three field seasons, the objective was to prepare maps of the Quaternary (surficial) geology of that portion of northeast Alberta represented by NTS maps 74M and part of 74L.

Methodology

Surficial materials were interpreted on aerial photographs and subsequently verified on the ground during field studies. Ground observations were entered into a computer database and later used to create digital maps. Glacial drift samples were obtained for geochemical analysis, and 330 drift samples were analyzed for grain size, carbonate content, trace elements and base metals. This gave an average of one sample for every 30 km^2 of the study area. Also, eight bulk samples were analyzed for kimberlite indicator minerals.

Results

The drift samples were classified according to origin as till, glaciofluvial, glaciolacustrine and eolian. Inductively Coupled Plasma (ICP) analysis of 32 elements allowed statistically derived contour maps to be prepared. They show the spatial distribution of elements in the glacial drift. Gold anomalies in the area and the presence of kimberlite indicator minerals near Colin Lake warrant further study. In particular, detailed sampling of the meltwater system along the Colin Lake Moraine should be done, especially since the mineral may have travelled a considerable distance from a source in the northeast.

Ground observations showed that although the Precambrian Shield was extensively gouged by the Laurentide Ice Sheet during the last glaciation, it is now sparsely covered by glacial deposits. This contrasts with areas west of the Slave River that are underlain by Paleozoic sedimentary rocks. They are covered by extensive glacial and post-glacial deposits.

During the glacial maximum, the ice flow over the entire area was dominantly from the northeast. As the ice thinned during deglaciation, a distinct ice lobe developed within the Lake Athabasca trough in the southern part of the area. This lobe flowed mainly to the west where it converged along a lateral margin with ice from the north. The area of contact is marked by converging striae and a broad east-west band of glacial outwash and lake deposits which were deposited later.

When the ice front retreated to the east and northeast, glacial Lake McConnell was formed. It inundated the Slave River lowlands and the Lake Athabasca basin up to 305 m above sea level. Then, a major readvance of the ice front produced the Slave moraine. Further retreat of the ice front across the Shield diverted meltwater along the ice margin. This created numerous ephemeral lakes and extensively redistributed the drift.

Publications/Presentations

Bednarski, J.M. 1996. Quaternary geology along the Shield margin, northeastern Alberta. Geological Survey of Canada Bulletin (R.W. Macqueen, editor). In press.

Bednarski, J.M. 1995a. Surficial geology, northeastern Alberta (NTS 74M and part of 74L). Geological Survey of Canada. A-series map (1:100 000). In prep.

Bednarski, J.M. 1995b. Application of Quaternary mapping to mineral exploration, northeastern Alberta. Program and Abstracts. Fourth Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. April 6–7, 1995. Calgary, Alberta.

Bednarski, J.M. 1995c. Surficial geology, Colin Lake, Alberta-Saskatchewan (NTS 74M/9). Geological Survey of Canada. Open File Report 3041. 1:50 000 geological map.

Bednarski, J.M. 1994a. Surficial geology, Andrew Lake, Alberta-Saskatchewan-Northwest Territories (74M/16). Geological Survey of Canada. Open File Report 2982. 1:50 000 geological map.

Bednarski, J.M. 1994b. Geochemistry of surficial materials in northeastern Alberta (NTS 74L,M). Abstract and Poster

Presentation. Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Annual General Meeting. May 2–4, 1994. Toronto, Ontario.

Bednarski, J.M. 1994c. Geochemistry and surficial materials in northeastern Alberta (NTS 74L and 74M). Program and Abstracts. Third Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. February 10–11, 1994. Calgary, Alberta. p. 47.

Bednarski, J.M. 1993a. Geochemistry of surficial deposits in northeastern Alberta. Geological Survey of Canada. Open File Report 2747.

Bednarski, J.M. 1993b. Quaternary geology and till geochemistry of the Precambrian Shield of Alberta. Program and Abstracts. The Calgary Mining Forum. Calgary Mineral Exploration Group Society. March 3–4, 1993. Calgary, Alberta. p. 13. *Also*: Canadian Institute of Mining Bulletin, 86:968. pp. 68–69.

Bednarski, J.M. 1993c. Preliminary report of the Quaternary geology of the Canadian Shield of northeastern Alberta Current Research Part E. Geological Survey of Canada. Paper 93-1E. pp. 191–196.

Bednarski, J.M. 1993d. Quaternary geology of the Precam brian Shield of Alberta. Program and Abstracts. Geological Association of Canada/Mineralogical Association of Canada Joint Annual Meeting, Edmonton, Alberta, May 17–19 [illegible] p. A7.

Bednarski, J.M, B.W. Charbonneau, C.-J.F. Chung, P.W.B Friske, M.R. McDonough and A.N Rencz. 1993. Northeastern Alberta MDA project, an integrated Geological Survey of Canada Study: highlights of proposed work for 1993–1994 Canadian Institute of Mining Bulletin, 86:968. p. 69.

Charbonneau, B.W., C.-J.F. Chung, J.M. Bednarski, P.W.B Friske, M.R. McDonough, P. An, A. Rencz and M.I. Lega[illegible] 1994. Integrated geoscience surveys of northeastern Alber[illegible] application to mineral potential assessment. Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Annual General Meeting. May 2–4, 1994. Toronto, Ontario.

Lemmen, D.S., A. Duk-Rodkin and J.M. Bednarski. 1994 Late glacial drainage systems along the northwest margin of the Laurentide Ice Sheet. Quaternary Science Reviews. Vol. 13. pp. 805–828.

McDonough, M.R., T.W. Grover, V.J. McNicoll, M.A. Cooley, E.M. Schetselaar, N.N. Robinson and J.M. Bednarski 1994. Geology, Colin Lake, Alberta-Saskatchewan (74M/9 Geological Survey of Canada. Open File Report 3047. Colour map (1:50 000).

Airborne Gamma-ray Spectrometer-Magnetic-VLF Plus Interpretation and Follow-up

Geological Survey of Canada, Ottawa

Project C1.14

Systematic airborne geophysical surveys can provide useful information for mapping and exploration. This knowledge can assist in understanding the distribution of bedrock and surficial features, as well as determine anomalies that might indicate commercially significant mineral deposits.

It is known that potential exists in northeastern Alberta for discovering deposits of uranium, molybdenum, copper, tin, tungsten, rare earth elements and gold. Thus, a project was [illegible] carry out an airborne survey of a 10 000 km^2 area between the west end of Lake Athabasca and the Alberta/ Northwest Territories boundary. This survey was supported by a ground investigation comprising geological observations, rock sampling and ground-based geophysical measurements.

Methodology

[illegible]rborne data were gathered along east-west lines spaced 1 km apart. In addition to using a gamma-ray spectrometer, the detection system included a proton precession magnetometer [illegible] Very Low Frequency-Electromagnetic (VLF-EM) sensor. Given the close spacing of the data points, this combination of detectors obtained information that was greatly improved over the results of previous surveys, some of which were carried out [illegible] 5-km intervals. The VLF data represents a new type of survey [illegible] Since all the data were acquired digitally, the results [illegible] with other data sets and for modelling.

[illegible]

[illegible]tal survey data are available on 3.5" diskettes suitable [illegible] MS Windows 3.1. A hard-copy booklet is also [illegible]ilable. It contains maps and profiles at 1:250 000 scale. This [illegible]oklet has 12 colour geophysical maps, a geological compila-[illegible]d mineral occurrence map, and a complete set of stacked, multiparameter geophysical profiles for each flight line.

The gamma spectrometer data are presented as a set of eight colour maps, one each for the following parameters:

- ternary radioelement;
- exposure;
- potassium
- equivalent uranium;

- equivalent thorium concentration;
- eu/eTh ratio;
- eu/K ratio; and
- eTh/K ratio.

The aeromagnetic data are presented as colour maps of total field and calculated vertical magnetic gradient, while the VLF-EM data have been compiled into a total field colour map showing an overlay of total field profiles. Another total field colour map has an overlay of quadrature profiles. A colour geological map showing mineral occurrences completes the set.

The stacked profiles show many strong anomalies in thorium and uranium. The uranium, thorium and uranium/thorium ratio maps provide significant information over igneous rocks. The observed patterns of thorium and uranium/thorium ratio are controlled by monazite, which hosts most of the thorium and is generally accompanied by zircon. Most of the uranium is hosted by uraninite-uranothorianite.

Less evolved, thoriferous magmatic rocks have greater amounts of biotite (iron, magnesium, titanium) and monazite and zircon. By contrast, the more evolved magmatic rocks have lower thorium concentrations that correspond to less monazite and zircon. The significance of these anomalies is that more evolved granitoids may host granophile mineralization, such as tin and tungsten.

Areas of high potassium with an accompanying low ratio of thorium to potassium usually relate to thorium-depleted granitoids, but may also indicate potassium alteration. This could point to a mineralized system, possibly including gold.

The observed magnetic patterns are caused by changes in the amount of magnetite. Such maps are useful in delineating geological structure and faulting. The observed VLF patterns correlate with fractures, and sometimes indicate sulphide-rich conductors.

Radiometric anomalies, such as those found in this survey, can often be correlated with mineralization. Aside from uranium mineralized areas, linkages of this type could not be established for the Alberta survey from these results. More work needs to be done to determine the relationships between observed geophysical patterns and the existence of mineralized systems. The correlation of these data with other geoscience surveys supported by the MDA may eventually lead to such recognition.

Publications

Bednarski, J.M., B.W. Charbonneau, C.-J.F. Chung, P.W.B. Friske, M.R. McDonough and A.N. Rencz. 1993. Northeastern Alberta MDA project, an intregated GSC study: highlights of proposed work for 1993–94. Canadian Institute of Mining Bulletin. 85:968. March 1993. p. 69.

Charbonneau, B.W., P.B. Holman and R.J. Hetu. 1996. Airborne gamma-ray spectrometer-magnetic-VLF survey of northeastern Alberta. Geological Survey of Canada Bulletin (R.W. Macqueen, editor). In press.

Charbonneau, B.W., P.B. Holman and R.J. Hetu. 1994. Airborne geophysical survey of northeastern Alberta (gamma spectrometry-magnetics-VLF-EM). NTS 74L/14, 15; 74M/1-3, 6-11, 14-16. Geological Survey of Canada. Open File Report 2807. 12 colour maps and 146 stacked profiles.

Hetu, R.J. 1994. Airborne geophysical survey of northeastern Alberta. Geological Survey of Canada. Open File Report 2807. Digital data only.

Shives, R.B.K., K.L. Ford and B.W. Charbonneau. 1995. Application of gamma-ray spectrometry-magnetic-VLF-EM surveys, workshop manual. Geological Survey of Canada. Open File Report 3061. 82 pp.

Geochemical Surveys

Geological Survey of Canada, Ottawa

Project C1.15

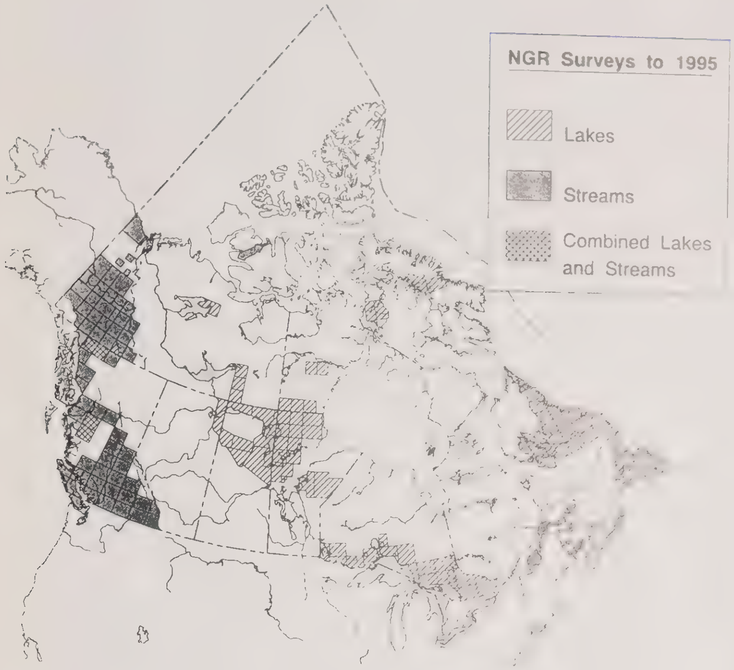
Lake-sediment geochemical data can indicate broad, regional trends of mineralization. When these data are combined with related geological information, a search for mineral deposits can be narrowed to specific areas.

Thus, the purpose of this project was to lend support to other studies of mineral potential in northeastern Alberta by carrying out a lake-sediment and water geochemical survey. Past experience has shown that similar surveys of lake sediments and waters are a cost-effective way for quickly evaluating the mineral potential of an area and stimulating mineral exploration activity.

During 1993, a lake-sediment and water geochemical survey was conducted over a 22 100 km^2 area. Samples were obtained at 1 160 sites, or one sampling site for every 19 km^2. The sampling and analysis procedures were consistent with those used in the National Geochemical Reconnaissance (NGR) program that has collected samples at more than 190 000 sites in Canada.

Methodology

Float-equipped helicopters served as platforms for collecting lake-sediment and water samples. Bottom-valved, hollow-pipe samplers were used. Sediments were analyzed for 35 elements plus loss-on-ignition. Water samples were analyzed for pH, fluoride and uranium.



Areas of Canada covered by lake and/or stream sediment surveys

Index map showing the area of Alberta covered by an [illegible]diment and water geochemical survey [illegible] carried out in 1993

Results

Data listings and statistics were prepared, and two types of maps were produced: a sample-location map showing background geology; and a small map for each element and its concentration.

It was found that the analytical results pertaining to the area north of Lake Athabasca varied considerably from those south of the lake. Whereas bedrock and structural geology control the geochemical results north of Lake Athabasca, the geochemistry of areas south of the lake is largely determined by past glacial processes. The geochemical profiles indicate that a moderate potential for uranium exists, particularly in the northern portion of the survey area. This potential is associated with fault intersections in Slave province granitoid rocks and within high-grade metasedimentary rocks.

Also, there is some potential for gold, including the possibility of placer deposits over areas of Athabasca sandstone. In addition, above-average gold values in the northern part of the survey area suggest that some gold deposits might be hosted in shear zones.

A closer examination of the granitoid rocks north of Johnson Lake is recommended, since this area has an unusually high antimony value and an associated gold anomaly.

Publications

Bednarski, J.M., B.W. Charbonneau, C.-J.F. Chung, P.W.B. Friske, M.R. McDonough and A.N. Rencz. 1993. Northeastern Alberta MDA project, an integrated Geological Survey of Canada study; highlights of proposed work for 1993–94. Canadian Institute of Mining Bulletin, 86:968. p. 69.

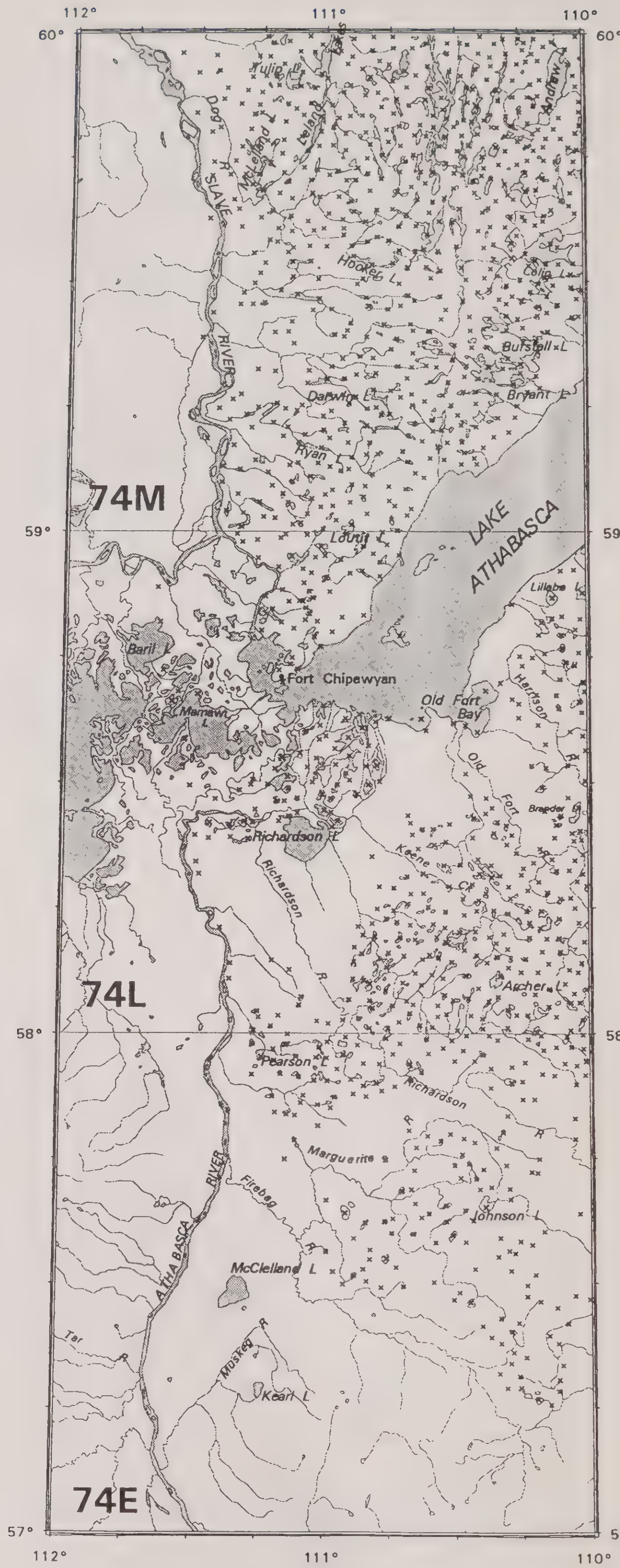
Friske, P.W.B, M.W. McCurdy, S.J. Day, H. Gross, R.G. Balma, J.J. Lynch and C.C. Durham. 1994. National Geochemical Reconnaissance lake sediment and water data, northeastern Alberta (parts of NTS 74E, 74L and 74M). Geological Survey of Canada. Open File Report 2856. 44 maps. [illegible]

McCurdy, M.W. 1996. Interpretation of geochemical data from lake sediments and waters over Precambrian rocks in northeast Alberta (NTS 74E, 74L, 74M.). Geological Survey of Canada Bulletin (R.W. Macqueen, editor). In press.

Element			Detection level		Method
Sediments:	Ag	Silver	0.2	ppm	AAS
	As	Arsenic	0.5	ppm	INAA
	Au	Gold	2	ppb	INAA
	AuWt	Sample Weight	0.01	g	–
	Ba	Barium	50	ppm	INAA
	Br	Bromine	0.5	ppm	INAA
	Cd	Cadmium	0.2	ppm	AAS
	Ce	Cerium	5	ppm	INAA
	Co	Cobalt	2	ppm	AAS
	Co	Cobalt	5	ppm	INAA
	Cr	Chromium	20	ppm	INAA
	Cs	Cesium	0.5	ppm	INAA
	Cu	Copper	2	ppm	AAS
	Eu	Europium	1	ppm	INAA
	F	Fluorine	40	ppm	ISE
	Fe	Iron	0.02	pct	AAS
	Fe	Iron	0.2	pct	INAA
	Hf	Hafnium	1	ppm	INAA
	Hg	Mercury	5	ppb	CV-AAS
	La	Lanthanum	2	ppm	INAA
	LOI	Loss-on-ignition	1.0	pct	GRAV
	Lu	Lutetium	0.2	ppm	INAA
	Mn	Manganese	5	ppm	AAS
	Mo	Molybdenum	2	ppm	AAS
	Na	Sodium	0.02	pct	INAA
	Ni	Nickel	2	ppm	AAS
	Pb	Lead	2	ppm	AAS
	Rb	Rubidium	5	ppm	INAA
	Sb	Antimony	0.1	ppm	INAA
	Sc	Scandium	0.2	ppm	INAA
	Sm	Samarium	0.1	ppm	INAA
	Ta	Tantalum	0.5	ppm	INAA
	Tb	Terbium	0.5	ppm	INAA
	Th	Thorium	0.2	ppm	INAA
	U	Uranium	0.2	ppm	INAA
	V	Vanadium	5	ppm	AAS
	W	Tungsten	1	ppm	INAA
	Yb	Ytterbium	1	ppm	INAA
	Zn	Zinc	2	ppm	AAS
Waters:	F-W	Fluoride	20	ppb	ISE
	pH	Hydrogen ion activity	–	–	GCM
	U-W	Uranium	0.05	ppb	LIF

AAS — atomic absorption spectrometry
CV-AAS — cold vapour/atomic absorption spectrometry
GCM — glass Calomel electrode and pH meter
GRAV — gravimetry
NAA — Instrumental Neutron Activation Analysis
ISE — ion selective electrode
LIF — laser-induced fluorescence

Summary of Analytical Data and Methods.



Map survey area showing sample sites for lake sediments and waters.

Data Integration, Northeastern Minerals Program

Geological Survey of Canada, Ottawa

Project C1.16

Considering the number of geoscience projects being carried out by both the Alberta Geological Survey and the Geological Survey of Canada in northeastern Alberta, it was decided to develop a computerized database that integrates the knowledge gained by this effort.

In this project, the objective was to develop a database that integrates spatial geological, geophysical and geochemical data that would be of value to the private sector in future mineral exploration. The database covers data that existed previously and new data resulting from the MDA projects.

The database includes the following:

- results from new geological mapping at 1:50 000 scale of bedrock and surficial features;
- data and interpretations from airborne gamma-ray, magnetic and VLF surveys;
- analytical results from a reconnaissance lake-sediment and water geochemical survey; and
- remotely sensed data from radar and multispectral LANDSAT™ imagery.

Results

At the close of the MDA program, analysis of the data was still under way. When the project is completed, the computer-based statistical and image-processing technology will be demonstrated to interested parties and then transferred to the Alberta Geological Survey.

Publications

Bednarski, J.M, B.W. Charbonneau, C.-J.F. Chung, P.W.B. Friske, M.R. McDonough and A.N. Rencz. 1993. Northeastern Alberta MDA project, an integrated Geological Survey of Canada Study: highlights of proposed work for 1993–1994 Canadian Institute of Mining Bulletin, 86:968. p.69.

Charbonneau, B.W., C.-J.F. Chung, J.M. Bednarski, P.W.B. Friske, M.R. McDonough, P. An, A.N. Rencz and M.I. Legault 1994. Integrated geoscience surveys of northeastern Alberta - application to mineral potential assessment. Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Annual General Meeting. May 2–4, 1994. Toronto, Ontario.

Chung, C.-J.F., A.N. Rencz and A. Zhang. 1996. Data integration study of mineral potential mapping in northeast Alberta. Geological Survey of Canada Bulletin (R.W. Macqueen, editor). In press.

Chung, C.-J.F., P. Gong and A.N. Rencz. 1993. Use of multispectral LANDSAT™ data for geological mapping in Precambrian Shield of northeastern Alberta. Canadian Institute of [illegible] Bulletin, 86:968. p. 69

[illegible] J.F. Chung. 1993. FAVMOD for integration of spatial geoscie[illegible] information. Geological Survey of Canada. Open File Report 2577. 88 pp

Mapping and Resource Exploration of the Tertiary Formations of Alberta

Alberta Geological Survey, Edmonton

Project M92-04-008

[illegible]l deposits produce most of [illegible]nd placer gold in Alberta. [illegible]duction from such deposits [illegible] placer gold from these deposits is [illegible]lued at $1 million. Furthermore, preglacial deposits represent [illegible]he only geological record of events that occurred on the Alberta [illegible]000 years ago. Considering [illegible] this project was initiated [illegible] more easily recognized. This could aid in [illegible]ploring for gold, diamonds and aggregate.

[illegible]es of the project were

- [illegible]lineate and describe sand and gravel deposits of [illegible]iary and preglacial age
- to correlate the deposits stratigraphically;
- to identify the occurrence and resource potential of placer [illegible]
- to identify deposits having potential for mineral aggregates; [illegible]
- to identify diamond-indicator minerals in these deposits.

[illegible]glacial deposits are usually identified according to cer[illegible]limentologic, stratigraphic and paleontologic criteria. [illegible]

- [illegible]omposed of interbedded sands and gravels [illegible]oss-bedding is common
- gravels do not contain granitic or gneissic clasts from the Precambrian Shield of northeastern Alberta, although the overlying tills or recent gravels often contain Shield clasts;

- gravels are composed of rock types — especially quartzites — occurring in the Rocky Mountains or Omenica Terranes;
- deposits rest unconformably on bedrock (intervening till is never present);
- deposits are often covered by till, glaciolacustrine or glaciofluvial materials, or Recent (Holocene) gravels; and
- deposits may contain horse or rhinoceros remains or those of other arid-plains mammals, or perhaps the remains of mammoths, indicating colder climates.

Methodology

Deposits thought to be preglacial were identified from the literature or Alberta Geological Survey files. Outlines of these deposits were digitized and then plotted on new maps. Each deposit was assigned an identification number.

From the digitized maps, certain deposits were selected for field examination. This included description of the deposits (including current directions) and collecting known weights and volumes of samples. These samples were then analyzed for grain size, petrography, gold content, heavy minerals and diamond-indicator minerals.

Results

A total of 221 preglacial deposits were identified. While 95 have either known or probable potential for mineral aggregates, 126 deposits have little potential or were still being assessed at the conclusion of the MDA program.

Grain size analyses indicated that all the deposits contain very coarse beds, and the gravel content ranged from 52 to 85 per cent. Grain size distribution indicated a predominance of gravel and medium-size sand. It is believed these deposits originated in fluvial environments. The current-direction analyses indicated flows from the southwest, west to northeast or east.

Petrographic analysis failed to find a suite of rocks that was common to all deposits. The deposits were divided into six groups, however, based on location and lithologic similarity. The deposits were further divided into four stratigraphic units, based on age and elevation. These units are: Cypress Hills Formation and equivalents; Hand Hills Formation and equivalents; Upland Gravels; and Saskatchewan Sands and Gravels.

Placer gold analyses indicated that deposits in central and northwestern Alberta contain the equivalent of 50 ounces or more of gold for every 100 000 tons of processed sand and gravel.

Two areas warrant further examination for diamonds. Samples from the Edmonton area yielded sufficient quantities of garnet, chromite and picroilmenite to suggest they might have originated in a diatreme having potential for diamonds. Also, the large number of chrome diopside grains in Peace River deposits may also indicate diamonds.

Publications

Edwards, W.A.D., D.R. Eccles, D.R. Boisvert and S.A. Miller. 1993a. Preglacial sand and gravel deposits, southern Alberta. Alberta Research Council Map 221.

Edwards, W.A.D., D.R. Eccles, D.R. Boisvert and S.A. Miller. 1993b. Preglacial sand and gravel deposits, central Alberta. Alberta Research Council Map 222.

Edwards, W.A.D., D.R. Eccles, D.R. Boisvert and S.A. Miller. 1993c. Preglacial sand and gravel deposits, northern Alberta. Alberta Research Council Map 223.

Edwards, W.A.D., D. Scafe, D.R. Eccles. S.A. Miller. T. Berezniuk and D.R. Boisvert. 1994. Mapping and Resource Exploration of the Tertiary and Preglacial Formations of Alberta. Alberta Research Council. Open File Report 1994-06. 61 pp., appendices and maps.

Investigation of Potential Paleoplacers in the Cretaceous Strata of the North Saskatchewan River Watershed

GEO-ING Resource Consulting Ltd., Edmonton

Project M93-04-031

Since gold was first discovered in the North Saskatchewan River more than a century ago, at least one tonne of the precious metal has been removed by panning and sluicing operations over much of the river's length. While it is recognized that the gold originated somewhere else and was carried by river currents to wherever it was found, the exact origin has never been located. Previous geological surveys in Alberta, along with experience gained elsewhere in the world, have indicated that certain strata in the Rocky Mountains probably host the paleoplacers that supply this gold. The objective of this survey was to investigate the most likely sources.

Background

All the major rivers that flow from the mountains and foothills of Alberta contain some gold. The North Saskatchewan River

has the highest concentration of gold-bearing sediment, with various locations along the river reporting concentrations ranging from 13 to 141 parts per billion (ppb). It is believed that the gold comes from paleoplacers (fossil placers) which are ancient deposits that were buried by younger sediments or volcanic rocks and then consolidated or even metamorphosed to some extent.

Two types of paleoplacers have been identified. The Edmonton Formation, along the North Saskatchewan River, is an example of the most common type, called moderately lithified. The other type, called extensively lithified, is much rarer. An example is the Witswatersrand conglomerate in South Africa, which has a gold content ranging from 400 to 230 000 ppb.

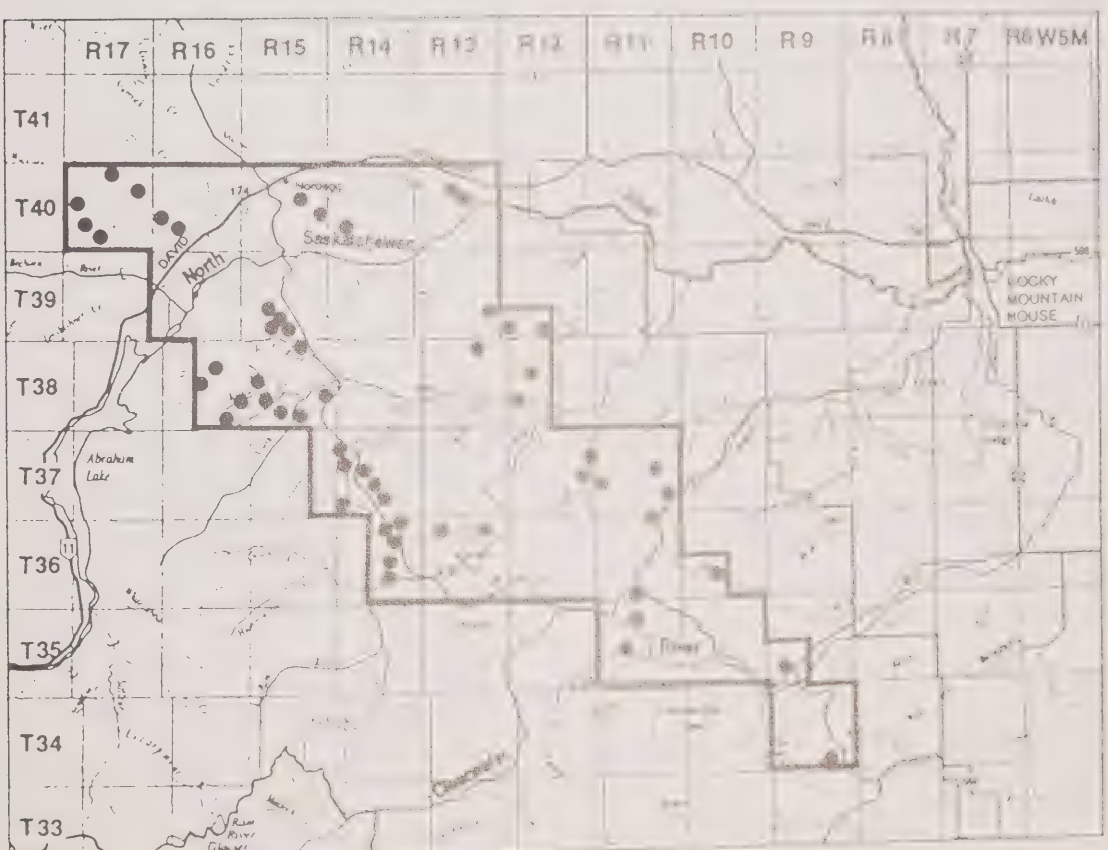
It is believed that suitable conditions for the development of paleoplacers in Alberta began approximately 140 million years ago during the Cretaceous Period when a mountain-building event (orogeny) lifted the Omineca and Rocky Mountain belts of the eastern Cordillera. These two belts are suspected of being the source of all gold found in Alberta and British Columbia, and these gold deposits are thought to be associated with plutonic and volcanic events.

Experience has shown that certain levels of volcanic grains in strata have proven to be good indicators of placer gold. In Alberta, these conditions exist in Cadomin, Hoadley, Mountain Park and Entrance conglomerates, as well as in coarse sandstones and conglomerates of the Brazeau Formation. In these materials, the volcanic grain content ranges up to 60 per cent.

Study Methodology

During 1993, 133 rock samples were collected from 92 sites in the southern half of the foothills segment of the North Saskatchewan River watershed. More specifically, the area was between the North Saskatchewan and Clearwater rivers south of Nordegg. The sample sources are as follows:

• Brazeau Formation	76 samples; 61 sites
• Cadomin Formation	47 samples; 25 sites
• Hoadley Conglomerate	6 samples; 3 sites
• Mountain Park Formation	3 samples; 3 sites
• Paskapoo Formation	1 sample



North Saskatchewan River Watershed Study: Sample Location Map.

The location of each sample was plotted on National Topographic Series maps and Resource Access maps, both of which are 1:50 000 scale.

All samples were analyzed for gold content by Fire Assay.

Results

Most of the samples contained less than 5 ppb of gold. This is regarded as a "background level," which is often the level of gold in ordinary shales and sandstones. Generally, deposits having less than 100 ppb are considered to be uneconomic. Only 13 samples had more than 5 ppb of gold, the highest being two samples from the Cadomin Conglomerate, having an assay of 16 ppb. One sample from the Brazeau Formation contained 13 ppb of gold.

Details about each sample, its location and the assay results are provided in the project final report.

Conclusions

It was concluded that the elevated levels of gold in the Cadomin and Brazeau formations partly support the belief that Cretaceous strata are the source of gold in the North Saskatchewan River.

It was recommended that future exploration should be concentrated on the Cadomin and Brazeau outcrops having the highest gold levels. In addition, it might be wise to sample some Upper Brazeau sandstones in the Kiska Mountain and Blackstone River area, as well as the Entrance Conglomerate in the Alexo-Saunders area to determine whether higher gold levels can be found.

Publication

Horachek, Y. 1994. Investigation of Potential Paleoplacers in the Cretaceous Strata of the North Saskatchewan River Watershed. GEO-ING Resource Consulting Ltd. 29 pp., appendices, maps.

Orientation Studies on Heavy Mineral Concentrates, and Ground-Penetrating Radar Studies

Geological Survey of Canada, Ottawa

Project C1.51

One way to improve any evaluation of sand and gravel reserves or potential placer gold deposits is to conduct heavy-mineral concentrate (HMC) studies, combined with the use of ground-penetrating radar. These techniques were used in selected stream drainage areas of the North Saskatchewan, Athabasca, McLeod and Peace river systems. Specifically, the study areas were located on NTS maps 75E (Vermilion), 83G (Wabamun Lake), 83H (Edmonton) and 83I (Tawatinaw).

The objectives of the project were:

- to identify, characterize and document gold and platinum group elements and their associated heavy mineral suite; and
- to test and interpret the ability of ground-penetrating radar to map HMC accumulations in the third dimension and potential deposition sites in surficial materials and at the bedrock interface.

Methodology

Before the project began, data had been gathered for more than 25 years on the distribution and concentration of placer gold deposits in parts of the four river systems. To extend this database, bulk samples of surficial material, aggregates and preglacial sand and gravel were collected for analysis. The "minus 65" fraction was analyzed, and a heavy mineral concentrate from that fraction was examined by scanning electron microscopy for mineralogy and composition of minerals.

Ground-penetrating radar was used at selected aggregate-placer sites to test its ability to detect subsurface sand or gravel beds and layers of heavy mineral concentrates.

Results

The gravels, which varied in age from Tertiary to Recent, were known to contain heavy minerals, including gold and platinum group elements. At the close of the MDA program, the analysis results were being compared with those from a platinum- and gold-bearing gravel deposit in Yukon. Also, photographic imaging was under way of complex gold and platinum group alloys in grains recovered from the heavy mineral concentrates.

Ground-penetrating radar showed promise for stratigraphic mapping of heavy mineral zones in some gravels. While the study was under way, geological consultants, pit operators and industry contractors gained field experience in using this technology.

Overall, the project provided new baseline information on the dispersion and accumulation patterns of gold, platinum group elements and heavy minerals.

Publications

Ballantyne, S.B. and R.C. Day. 1993. Canada-Alberta MDA orientation studies program. Program and Abstracts. The Calgary Mining Forum. Calgary Mineral Exploration Group Society. March 3–4, 1993. p. 13. Calgary, Alberta. *Also*: Canadian Institute of Mining Bulletin. 86:968. p. 69.

Ballantyne, S.B. and D.C. Harris. 1996. Alluvial platinum-group minerals and gold in Alberta: results from the "orientation studies project" and their exploration significance. Geological Survey of Canada Bulletin (R.W. Macqueen, editor). In press.

Ballantyne, S.B. and D.C. Harris. 1995. Alberta orientation: the big picture. Program and Abstracts. Fourth Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. April 6–7, 1995. Calgary, Alberta.

Ballantyne, S.B. and D.C. Harris. 1994a. The exploration significance of central Alberta Modern and Tertiary alluvial platinum group metals, chromites, ilmenites and placer gold. Program and Abstracts. Third Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. February 10–11, 1994. p. 33. Calgary, Alberta.

Ballantyne, S.B. and D.C. Harris. 1994b. Exploration significance of placer platinum group minerals, chromite and gold, central Alberta. Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Annual General Meeting. May 2–4, 1994. Toronto, Ontario.

Ballantyne, S.B., D.C. Harris and S.F. Sabag. 1995. Mineralogical results from insoluble residues obtained from cold HF digestion of precious metal-bearing strata, Fort MacKay, Alberta. Geological Survey of Canada. Abstracts 1995. pp. 21,22.

Ballantyne, S.B., D.C. Harris, A. Panteleyev and S.F. Sabag. 1995. "Definitely not pollution:" Canadian geologic settings for native assemblages of endogenic and exogenic origins. Geological Survey of Canada. Forum 1995. Abstract. p. 5.

Harris, D.C. and S.B. Ballantyne. 1994. Characterization of gold and PGE-bearing placer concentrates from the North Saskatchewan River, Edmonton, Alberta. Current Research 1994-E. Geological Survey of Canada. pp. 133–139.

Regional Synthesis of the Structural and Stratigraphic Setting of Alberta to Assist Industry in Their Search for Diamondiferous Diatremes

APEX Geoscience Ltd. (Edmonton), University of Alberta (Edmonton), Elad Enterprises Ltd. (Calgary) and Alberta Geological Survey, (Edmonton)

Project M93-04-037

The current claim-staking activity being experienced in Canada began soon after diamonds were discovered in 1991 in Northwest Territories. Given the geology of the area, its close proximity to Alberta and reported discoveries of indicator minerals and structures within Alberta, there is considerable interest in trying to find diamonds in the province. Nonetheless, little exploration for diamonds in Alberta has been done in the past, and the results of some work have been kept confidential. Consequently, this study was undertaken to provide a publicly available, geological framework for future investigations.

Background

It is believed that diamonds originated approximately a billion or more years ago at temperatures not exceeding 1 200°C and under high pressure within an upper zone of the Earth's mantle, called the lithosphere. This portion of the mantle is located 150–300 km beneath the Earth's surface. Through some type of magmatic eruption, diamonds and other minerals are transported relatively quickly (20–30 km/h) toward the surface, where cooling takes place. This leaves the diamonds and other materials embedded in igneous rock.

This rock is generally shaped like a long, vertical pipe or "carrot" called a diatreme that is a type of volcanic vent. Because diamonds would be converted to graphite if they were subjected to extremely high temperatures, it is believed their passage to the surface occurs along existing fractures and ruptures in the Earth's crust, and through a relatively thick and cool part of the lithosphere

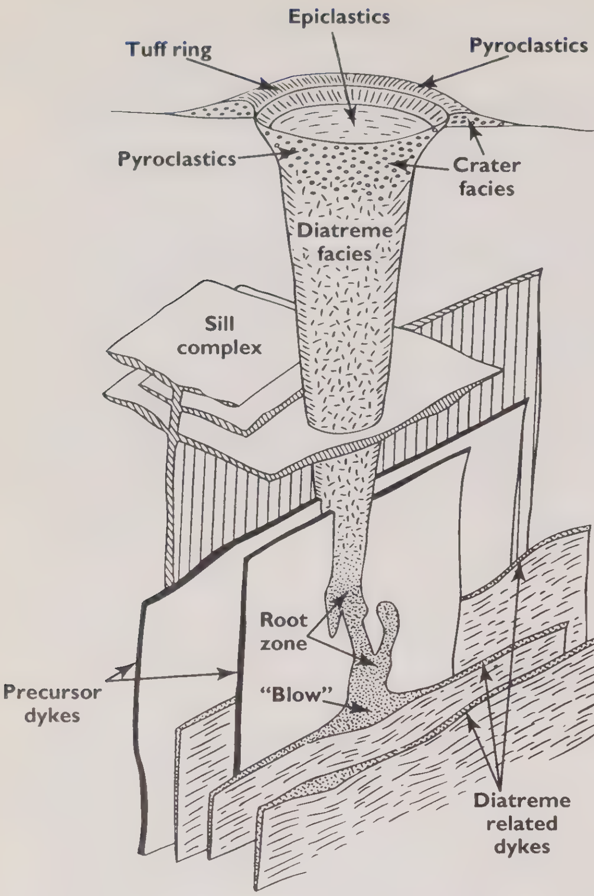
The most common diamond-hosting diatremes are called kimberlites and lamproites. Each has specific characteristics, but kimberlite is the more common source of diamonds. For example, kimberlite pipes are significant diamond sources in Botswana, Tanzania and South Africa.

Kimberlite pipes consist of three parts: a crater zone at the surface; a diatreme zone containing the main part of the diamond deposit; and a root zone, which may contain structures called diatreme dikes. Pipes are often found in clusters — six to 40 pipes per cluster have been found — and these clusters can be 40 km in diameter.

Usually, the crater zone has been eroded and is covered with till. The erosion products produce secondary deposits of diamonds, which have been found on river banks and even a beach.

The top part of a pipe can measure 500 m across. Diatremes may extend one or two kilometres beneath the surface, while the root zone may have a vertical height of 500 m.

It has been estimated that there may be 5 000 kimberlite occurrences worldwide, and kimberlites have been found on every continent except Antarctica.



Model of an idealized kimberlite magmatic system (not to scale) illustrating the relationships between crater, diatreme and hypabyssal facies rocks. The diatreme root zone is composed primarily of hypabyssal rocks (Mitchell, 1986).

Approximately 75 per cent of the world's diamonds come from kimberlite pipe deposits. Gem or near-gem diamonds comprise 30 per cent of these deposits, while the remainder can be used in industrial applications. Less than 25 per cent of all diamonds come from placer deposits, but 60 per cent are of gem quality.

Lamproites differ chemically from kimberlites and do not have the characteristic carrot shape. Instead, their vents are shallow and wide and are said to resemble a champagne glass.

Not all kimberlites and lamproites contain diamonds, however. Some originate at craton margins above diamond-bearing rocks, and therefore cannot transport diamonds to the surface.

It is generally accepted by geologists that diamonds in kimberlites or lamproites are xenocrysts, having been crystallized somewhere other than in the igneous rock where they are found, and they are derived from mantle peridotite or eclogite. Also, most peridotitic diamonds are believed to be Archean (4 000 to 2 500 million years old), whereas eclogitic diamonds can be as old as Archean or as young as 990 million years. Thus, the most favorable areas in Alberta for diamondiferous kimberlite or lamproite to have intruded should be those that are underlain by fault-bounded, basement structures called terranes comprising old, thick and cold crust that has not been subjected to thermal reheating through time.

The dominant minerals in the upper mantle are magnesium and iron silicates, along with pyroxene and garnet. These latter two minerals sometimes indicate the presence of diamonds. Also, anomalous deposits of bentonite indicate local volcanic activity, which may suggest the presence of diamonds.

It is generally agreed that four conditions must be met before a large, primary deposit of diamonds appears at the Earth's surface. They are:

- the kimberlite or lamproite host rock must originate in or below a diamond-rich source region of the mantle where diamonds have remained stable since they were formed;
- the kimberlite or lamproite intrusion must sample the diamond-bearing source region;
- the kimberlite or lamproite magma must ascend fast enough and provide a suitable reducing environment for diamonds to survive the trip to the Earth's surface; and
- the host magma must encounter emplacement sites where conditions are conducive to the formation of sufficiently large pipes.

Many explorational criteria must be examined to narrow any search for kimberlite or lamproite pipes. All pertinent criteria are described in considerable detail in the 400-page final report produced for this project. The report may be purchased from the Alberta Geological Survey.

Diamond-Related Considerations

Beginning with a description of Earth's structure and relationships among the inner core, mantle and other components, the authors of the final report then provide considerable information about numerous topics that are relevant to Alberta's geology and the existence of diamond-bearing structures.

Crust

Alberta is underlain by large areas of Precambrian crust, which is capable of providing the "cool roots" that geologists believe are needed for diamond formation. For example, seismic tomography and surface wave studies indicate that the upper mantle beneath Alberta is a transitional zone between the shal-

low, slow seismic velocities in the Cordillera and the deep, fast seismic velocities in the Canadian Shield. These readings are representative of hot and cool portions of the mantle, respectively. Supporting these observations are investigations that have shown that the lithosphere thickens to the north and east of Alberta.

Controlled-source seismic refraction experiments show that the Mohorovicic discontinuity (Moho) becomes more shallow in the northeastern areas of Alberta, and the crust in southern parts of Alberta (removed from the Rocky Mountains) is thicker than "normal" continental crust. The crust, however, appears to be thinner beneath the Southern Alberta Rift (also known as the Vulcan Low). Bouguer gravity measurements support the belief that the crust becomes thinner east of the mountains. Low Bouguer gravity readings appear to coincide with the Snowbird Tectonic Zone and the Southern Alberta Rift.

Magnetic data show the existence of major crustal features, such as the Great Slave Lake Shear Zone, the Snowbird Tectonic Zone and the Southern Alberta Rift.

Thus, it is concluded that diamond-bearing source rocks probably exist in parts of the mantle beneath Alberta.

Faults

Alberta has several major faults and other tectonic features that might have acted as near-surface conduits for the intrusion of diamond-bearing kimberlitic or lamproitic diatremes. The major structures of Precambrian age include the Great Slave Lake Shear Zone in northern Alberta, the Snowbird Tectonic Zone in central Alberta and the Southern Alberta Rift in southern Alberta. These features are believed to be Early Proterozoic (2 000–1 800 million years ago), but were periodically active throughout the Proterozoic period and into the Phanerozoic period, which began 590 million years ago.

Other tectonic features that were active and affected the deposition of Phanerozoic strata include: (1) the Peace River Arch in northwest Alberta; (2) the West Alberta Arch in western Alberta; (3) the Meadow Lake Escarpment in east-central Alberta; (4) the Sweet Grass Arch and Alberta Syncline in southern and western Alberta; (5) the Rocky Mountain Fold and Thrust Belt; (6) transverse, tear and normal faults in the Rocky Mountains and Foothills; and (7) fracturing and salt dissolution features in some parts of the Plains region, particularly in northeast Alberta.

Each of these features is discussed in detail in the project final report.

Nearby Diatremes

Kimberlites and lamproites occur on all major continents, and range in age from Lower Proterozoic to Recent. Kimberlites with economic concentrations of diamonds, regardless of age, occur almost exclusively on Archean cratons. The only known exception is the Argyle lamproite of Western Australia, which is on a Proterozoic craton.

Most of the important worldwide ages for kimberlite or lamproite magmatic events are represented on the North American continent. Kimberlite and lamproite intrusions, some of which are diamondiferous, exist in several provinces, territories and states adjacent to or near Alberta.

Considerable exploration activity has resulted from the discovery of kimberlite pipes (more than 60 pipes have been found thus far) in Northwest Territories at Lac de Gras. One known diatreme cluster straddles the British Columbia-Alberta border, and diamonds have been found in southern Alberta near the Sweetgrass Intrusions which might host diamonds. Similar formations are nearby in Montana. Also, diatremes have been found in south-central and northwest Saskatchewan.

Alberta's diamond potential.

Volcanic Activity

Alberta has experienced four, perhaps five, episodes of volcanic activity, and these periods correspond to the ages of diamondiferous diatremes found elsewhere. The ages of volcanic activity are Helikian, Late Devonian to Early Mississippian, Middle Cretaceous, Late Cretaceous and Early Tertiary. The most important of these may have occurred during the early part of the Late Cretaceous Period. This is the time when diamondiferous diatremes found in Saskatchewan were formed. However, the diatremes found at Lac de Gras have been dated to the Early Tertiary Period (52 million years ago). Therefore, strata from this period may have some potential.

The oldest examples of volcanic activity are represented by the Helikian Moyie Sills and Purcell Lavas in the Clark Range in southwest Alberta. Diatreme clusters straddling the Alberta-British Columbia border represent Late Devonian to Early Mississippian volcanic events. The third generation of volcanic activity in Alberta is represented by Middle Cretaceous Viking Formation bentonites and the Crowsnest Formation volcanics.

Bentonites are used as marker horizons across a large portion of Alberta and have an average radiometric age of 100 million years. The Crowsnest Volcanics, near Coleman in southwest Alberta, are 96 million years old. This is approximately the same age of several diamondiferous kimberlites found near Fort a la Corne, Saskatchewan. Therefore, Middle Cretaceous continental marine sedimentary rocks, such as those in the Viking Formation, may be potential hosts to diamond-bearing kimberlite or lamproite.

Indicators

Bentonites and tuff, which originated with volcanic activity, are found in several Alberta locations. Some are the volcanic debris that has drifted into Alberta from events occurring elsewhere, but others are anomalous and could indicate local volcanic activity. These bentonitic horizons are found near Drumheller, Duagh (north of Edmonton) and Irvine-Bullshead near Medicine Hat. All are dated to the late Late Cretaceous, which is the period when most events of diamondiferous magmatism occurred in the world.

Detailed sampling for diamond-indicator minerals in Alberta is currently under way. It is known that numerous diamond indicator-mineral anomalies exist in Alberta, and their chemistry is consistent with having been derived from kimberlitic or lamproitic diatremes. Also, diamonds have been found in drift or fluvial sediments at three locations in central and southern Alberta.

While data interpretation is still incomplete, several important trends have been recognized. These areas of interest are: (1) parallel to the the Milk River near the Alberta-Montana border; (2) an area between Brooks and the Saskatchewan border; (3) an area extending from the Saskatchewan border south of Provost to southwest of Oyen; (4) an area from Gleichen to Wabamum Lake; (5) an area southwest of Cold Lake in the vicinity of Vegreville; and (6) an area stretching from southeast of Hinton to west of Rocky Mountain House. Detailed locations are described in the project final report.

Other Indicators

There are numerous geological, geophysical or geochemical anomalies in Alberta, some of which may be related to emplacement of diamondiferous diatremes, or to the erosion of diamond-hosting rocks. Diamond potential may also be indicated by certain mineralogical and lithogeochemical anomalies. They include:

- fluorine in groundwater, which may be related either to volcanic activity or the leaching of bentonite;
- helium and other inert gases, such as carbon dioxide, with possible mantle-derived sources;
- marl anomalies, where it is currently not possible to distinguish between those formed by the weathering of kimberlites and lamproites and those derived from ordinary surficial or sedimentary processes;
- platinum group elements and gold in fluvial sediments, where they occur in concert with diamond indicator minerals;
- apparent salt solution collapse features, which are not spatially related to the salt dissolution edge or the erosional unconformities along the northeast edge of the Alberta Basin; and
- other geochemical and mineralogical anomalies, such as lithium, bromine and iodine in formation waters.

Conclusions

It was concluded that Alberta has moderate to high potential for hosting diamondiferous diatremes and vent-related deposits. However, little exploration for diamonds has occurred. The background and details in the report produced for this project should be an invaluable aid for further research on this subject.

Publications and Presentations

Dufresne, M.B. and D.R. Eccles. 1995. Regional synthesis of the structural and stratigraphic setting of Alberta to assist industry in their search for diamondiferous diatremes. Poster Presentation. Geological Survey of Canada Forum. January 1995. Ottawa, Ontario.

Dufresne, M.B., D.R. Eccles, R.A. Olson, M.M. Fenton, R.J.H. Richardson, D.R. Schmitt and B. McKinstry. 1994. The diamond potential of Alberta: a regional synthesis of the structural and stratigraphic setting and other preliminary indications of diamond potential. Poster Presentation. Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Annual General Meeting. May 2–4, 1994. Toronto, Ontario.

Dufresne, M.B., D.R. Eccles, D.R. Schmitt, B. McKinstry, M.M. Fenton and W.A.D. Edwards. 1996. The diamond potential of Alberta. Alberta Geological Survey Bulletin 63. In prep.

Dufresne, M.B., R.A. Olson, D.R. Schmitt, B. McKinstry, D.R. Eccles, M.M. Fenton, J.G. Pawlowicz, W.A.D. Edwards and R.J.H. Richardson. 1995a. The diamond potential of Alberta: a regional synthesis of the structural and stratigraphic setting and other preliminary indications of diamond potential. Poster Presentation. Cordilleran Roundup. February 1994. Vancouver, B.C.

Dufresne, M.B., R.A. Olson, D.R. Schmitt, B. McKinstry, D.R. Eccles, M.M. Fenton, J.G. Pawlowicz, W.A.D. Edwards and R.J.H. Richardson. 1995b. The diamond potential of Alberta: a regional synthesis of the structural and stratigraphic setting and other preliminary indications of diamond potential. Poster Presentation. Prospectors and Developers Association of Canada Annual General Meeting. March 1995. Toronto, Ontario.

Dufresne, M.B., R.A. Olson, D.R. Schmitt, B. McKinstry, D.R. Eccles, M.M. Fenton, J.G. Pawlowicz, W.A.D. Edwards and R.J.H. Richardson. 1994a. The diamond potential of Alberta: a regional synthesis of the structural and stratigraphic setting and other preliminary indications of diamond potential APEX Geoscience Ltd., University of Alberta, Elad Enterprises Ltd. and Alberta Geological Survey. Alberta Research Council. Open File Report 1994-10. 349 pp., appendices.

Dufresne, M.B., R.A. Olson, D.R. Schmitt, B. McKinstry, D.R. Eccles, M.M. Fenton, J.G. Pawlowicz, W.A.D. Edwards and R.J.H. Richardson. 1994b. The diamond potential of Alberta: a regional synthesis of the structural and stratigraphic setting and other preliminary indications of diamond potential. Poster Presentation. Third Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. February 10–11, 1994. Calgary, Alberta.

Kimberlite Mineralogy, Petrology and Geochemistry

Geological Survey of Canada, Ottawa

Project C1.31

Most diamondiferous kimberlites known throughout the world are associated with old (>2 400 million years), thick crust, which had become cratonized by 1 500 million years ago. Using these criteria, Alberta should be a prime location for kimberlites because it has major crustal domains that are at least 2 500 million years old. Slave, Hearne, Rae, Medicine Hat Block and Loverna Block rocks are this age and they occur on the surface and below the surface. In addition, regional tectonic events in Alberta predate 1 700 million years ago, implying that cratonization was complete long before 1 500 million years in the past.

This project was initiated to obtain more information about rocks having good potential for hosting diamonds in Alberta. The objectives were:

- to characterize mantle-derived potassic rocks (kimberlites, minettes) in Alberta and their entrained crustal and mantle xenoliths on a mineralogic, petrologic, geochemical and isotopic basis, and compare the results with those of other Canadian occurrences;
- to evaluate the economic potential of kimberlites on the basis of these parameters; and
- to establish a kimberlite heavy-mineral data base for Alberta.

Methodology

The study area was primarily limited to that represented by NTS maps 72E and 82H in southern Alberta.

Collected samples were analyzed by several techniques. Petrographic analysis was carried out to provide a textural-genetic facies classification, and electron microprobe analysis was conducted in conjunction with the petrologic work on individual minerals (megacrysts, phenocrysts and groundmass).

Major- and trace-element, whole-rock geochemistry was undertaken, and whole-rock radiogenic isotope analyses were carried out on selected samples.

Electron microscopy and proton microscopy of kimberlite heavy-mineral concentrates was used to evaluate the economic potential of kimberlite samples. Also, bench tests of resistivity, conductivity, magnetic susceptibility and gravity response were undertaken.

At the close of the MDA program, some data interpretation had not yet been completed.

Results

In 1992, seven minette bodies in the Sweetgrass Hills were examined. While earlier work suggested that they were dykes radiating from main intrusive centres in northern Montana, the results of this investigation indicate that the Sweetgrass minettes are discrete, small volcanic vents. Major- and trace-element chemistry, mineralogy and mineral chemistry of whole-rock samples confirm that these rocks are minettes and are similar to other minettes from the Montana alkaline province.

Considering the important role that indicator minerals play in diamond prospecting, a database of indicator-mineral compositions for Alberta kimberlites is being created for comparison with results from other kimberlite studies in North America.

Since the Sweetgrass rocks had not been studied by modern petrologic methods before this project, and they are known to contain abundant Precambrian crustal xenoliths and mantle xenoliths, the results should provide important information about the buried Archean Medicine Hat Block.

Publications

Davis, W.J. and B.A. Kjarsgaard. 1994. A Rb-Sr phlogopite-whole rock isochron age for olivine minette from the Milk River area, southern Alberta. Current Research 1994-F. Radiogenic Age and Isotopic Studies. Report 8. Geological Survey of Canada. pp. 11–14.

Kjarsgaard, B.A. 1996. Diamonds in Alberta: studies of potential host rocks of deep-seated origin and applications of indicator mineral exploration techniques. Geological Survey of Canada Bulletin (R.W. Macqueen, editor). In press.

Kjarsgaard, B.A. 1995. An overview of the occurrence and distribution of kimberlites in Canada. Geological Survey of Canada. Forum 1995. Abstracts. p. 19.

Kjarsgaard, B.A. 1994a. Potassic magmatism in the Milk River area, southern Alberta: petrology and economic potential. Current Research 1994-B. Geological Survey of Canada. pp. 59–68.

Kjarsgaard, B.A. 1994b. Potassic magmatism in the Sweetgrass Hills, southern Alberta and implications for diamond exploration. Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Annual General Meeting. May 2–4, 1994. Toronto, Ontario.

Kjarsgaard, B.A. 1993a. Petrology of the Sweetgrass Minettes, southern Alberta. Canadian Institute of Mining Bulletin, 86:968. p.57. *Also:* 95th Annual General Meeting and 44th Annual Technical Meeting of the Canadian Institute of Mining, Metallurgy and Petroleum. May 9–12, 1993. Calgary, Alberta.

Kjarsgaard, B.A. 1993b. Kimberlite, lamproite, diamond. Program and Abstracts. The Calgary Mining Forum. Calgary Mineral Exploration Group Society. March 3–4, 1993. Calgary, Alberta.

Kjarsgaard, B.A. 1993c. Recalibration of the Ni garnet/olivine exchange thermometer, with applications. Canadian Institute of Mining Bulletin. 86:968. p. 69. *Also:* Program and Abstracts. Geological Association of Canada/Mineralogical Association of Canada Joint Annual Meeting. May 17–19, 1993. p. A-53. Edmonton, Alberta.

Kjarsgaard, B.A. and W.D. Davis. 1994. Eocene magmatism in the Sweetgrass Hills and its tectonic significance. *In*: Ross, G.M (ed). LITHOPROBE Alberta Basement Transects Workshop (February 14–15). LITHOPROBE Report #37. LITHOPROBE Secretariat. University of British Columbia. pp. 234–237.

Mariano, J., R. Dumont, B.A. Kjarsgaard and D. Teskey. 1994. Detecting alkaline intrusive rocks in southern Alberta with low-level aeromagnetic data. Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Annual General Meeting. May 2–4, 1994. Toronto, Ontario.

Aeromagnetic Survey: Cypress Hills

Geological Survey of Canada, Ottawa

Project C1.33

Aeromagnetic surveys are capable of gathering information that can be useful when exploring for diamondiferous kimberlites. These data can also help locate intrasedimentary anomalies and define basement structures of importance in structural framework studies and in hydrocarbon exploration.

Consequently, this project was initiated with the objective of performing an aeromagnetic total-field survey of the Cypress Hills area of southern Alberta, as represented by NTS map 72E and parts of 82H.

Methodology

The survey was flown on east-west lines spaced 0.8 km apart at a height above ground of 150 m, with control spacing at 5 km. These specifications are typical of those used in Canadian Shield aeromagnetic surveys. (This is the first survey of its kind having publicly available results that has been flown in the Western Canadian Basin to this level of detail.)

Results

The survey was completed in 1992 and the results were released to the public in 1993 as digital data, a series of black and white 1:100 000-scale line contour maps, and six 1:100 000-scale colour contour maps. The high quality and detail of the results are generating much interest among mineral and hydrocarbon explorationists.

Publications

Dumont, R., P. Stone and D. Teskey. 1993. Aeromagnetic survey, Cypress Hills. Canadian Institute of Mining Bulletin. 86:968. p. 69. *Also:* Program and Abstracts. Geological Association of Canada/Mineralogical Association of Canada Joint Annual Meeting. May 17–19, 1993. p. A-25. Edmonton, Alberta.

Ross, G.M., J. Mariano and R. Dumont. 1994. Was eocene magmatism widespread in the subsurface of southern Alberta? *In*: Ross, G.M. (ed). LITHOPROBE Alberta Basement Transects Workshop (Feb 14, 15). LITHOPROBE Report #37. LITHOPROBE Secretariat. University of British Columbia. pp. 240–249.

Ross, G.M., J. Mariano, R. Dumont, B. Kjarsgaard and D. Teskey. 1996. Was Eocene magmatism widespread in the subsurface of southern Alberta? Evidence from new aeromagnetic anomaly data. Geological Survey of Canada Bulletin (R.W. Macqueen, editor). In press.

Stone, P.E. 1993a. High resolution aeromagnetic total field survey of the Cypress Hills area, Alberta. 6 sheets (black and white). Scale 1:100 000. May 7. Geological Survey of Canada Open File Report 2588. Map 1 — 82H/NE (south half); Map 2 — 72E/NW; Map 3 — 72E/NE; Map 4 — 82H/SE; Map 5 — 72E/SW; Map 6 — 72E/SE.

Stone, P.E. 1993b. Coloured maps: aeromagnetic residual total field colour interval maps with line contours, Cypress Hills area, southern Alberta. Scale 1:100 000. Map C9865G — 82H/NE (south half); Map C9866G — 72E/NW; Map C9867G 72E/NE; Map C9868G — 82H/SE; Map C9869G — 72E/SW; Map C9870G — 72E/SE.

Digital data for these maps may be obtained from the Geophysical Data Centre, 1 Observatory Crescent, Ottawa, Ontario, K1A 0Y3. Telephone: (613) 995-5326. Fax: (613) 992-2787.

Geochemical and Mineralogical Reconnaissance

Geological Survey of Canada, Ottawa

Project C1.32

The objectives of this project were to gather information about the till characteristics, geochemistry and the presence (or absence) of diamond-indicator minerals in southern Alberta. A similar study (*Reconnaissance Mineral and Geochemical Survey with Emphasis on Northern Alberta*) was carried out in northern Alberta by the Alberta Geological Survey, and both projects used the same sample-collection and analytical methods.

Methodology

Sampling was carried out over a 200 000 km^2 area bounded on the south by the international boundary, on the east by the Alberta-Saskatchewan border, on the west by Pincher Creek, Rocky Mountain House and Whitecourt, and on the north by Athabasca and Lac La Biche. Altogether, sampling was done at 604 sites. At 252 of these, 25-kg samples were taken of unsorted glacial sediments for provenance, mineralogical and geochemical studies. At 352 sites, 2-kg samples were taken of both A and C horizon soils. They were analyzed solely for geochemistry.

Results

This was the first systematic study of indicator minerals, geochemistry and sediment composition in southern Alberta. The major findings were as follows:

- a non-random distribution of diamond-indicator minerals in surface till was observed for Cr-pyrope, Cr-diopside, Mg-ilmenite and gold;
- till geochemistry, pebble lithology and the bulk mineralogy of heavy minerals vary systematically across the region, indicating a derivation mostly from the northeast, but also from the Cordillera for areas near Calgary; and
- ultra-low density, soil-geochemical data provide a useful regional background for more detailed mineral exploration and for environmental and agricultural investigations.

Publications

Garrett, R.G. 1994. The distribution of cadmium in A horizon soils in the prairies of Canada and adjoining United States. Current Research. Geological Survey of Canada. Paper 1994-B. pp. 73–82.

Garrett, R.G. and L.H. Thorleifson. 1995. Investigations into trace-element bioavailability in selected prairie soils. Geological Survey of Canada. Current Activities Forum. Abstracts 1995. p. 24.

Garrett, R.G. and L.H. Thorleifson. 1994a. Glacial transport history of indicator minerals in the Canadian prairie region: evidence from till composition. Program and Abstracts. Third Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. February 10–11, 1994. p. 49. Calgary, Alberta.

Garrett, R.G. and L.H. Thorleifson. 1994b. Kimberlite indicator mineral reconnaissance of the Canadian prairie. Prospectors and Developers Association of Canada Annual Meeting. March 6–9, 1994. Toronto, Ontario.

Garrett, R.G. and L.H. Thorleifson. 1993a. Prairie kimberlite study — soil and till geochemistry and mineralogy, low density orientation survey traverses, Winnipeg-Calgary-Edmonton-Winnipeg, 1991. Geological Survey of Canada Open File Report 2685. One diskette.

Garrett, R.G. and L.H. Thorleifson. 1993b. Prairie indicator mineral and soil geochemical survey. Program and Abstracts. The Calgary Mining Forum. Calgary Mineral Exploration Group Society. March 3–4, 1993. p.32. Calgary, Alberta.

Thorleifson, L.H. 1993c. Kimberlite indicator mineral tracing on the Canadian prairie. Program and Abstracts. The Calgary Mining Forum. Calgary Mineral Exploration Group Society, March 3–4, 1993. p. 14. *Also*: Canadian Institute of Mining Bulletin. 86:968. p. 70.

Thorleifson, L.H. 1993d. Provenance of heavy minerals on the Canadian prairie. Program and Abstracts. Geological Association of Canada/Mineralogical Association of Canada Joint Annual Meeting. March 17–19, 1993. p. A-104. Edmonton, Alberta.

Thorleifson, L.H. and R.G. Garrett. 1996. Kimberlite indicator mineral and geochemical reconnaissance of southern Alberta. Geological Survey of Canada Bulletin (R.W. Macqueen, editor). In press.

Thorleifson, L.H. and R.G Garrett. 1995a. Prairie kimberlite study: progress in drift provenance, mineral classification and geochemical studies. Geological Survey of Canada. Current Activities Forum. Abstracts 1995. p. 20.

Thorleifson, L.H. and R.G Garrett. 1995b. Prairie geochemical reconnaissance: gold in soil and till. Program and Abstracts. The Fourth Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. April 6–7, 1995. Calgary, Alberta.

Thorleifson, L.H. and R.G. Garrett. 1994a. Kimberlite indicator reconnaissance of the Canadian prairie. Geological Survey of Canada. Minerals Colloquium. January 17–19, 1994. Ottawa, Ontario.

Thorleifson, L.H. and R.G. Garrett. 1994b. Indicator mineral reconnaissance of the Canadian prairies. Program and Abstracts. Third Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. February 10–11, 1994. p. 48. *Also:* Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Annual General Meeting. May 2–4, 1994. Toronto, Ontario.

Thorleifson, L.H. and R.G. Garrett. 1993. Prairie kimberlite study — till matrix geochemistry and preliminary indicator mineral data. Geological Survey of Canada Open File Report 2745. One diskette.

Thorleifson, L.H., R.G. Garrett and G. Matile. 1994. Prairie kimberlite study — indicator mineral geochemistry. Geological Survey of Canada. Open File Report 2875. One diskette.

Reconnaissance Mineral and Geochemical Survey with Emphasis on Northern Alberta

Alberta Geological Survey, Edmonton

Project M92-04-006

Since the discovery of diamonds in Northwest Territories, the northern part of Alberta has been targeted by explorationists as a possible site for more diamond finds. However, the area has not been adequately characterized in terms of till characteristics, geochemistry and the presence (or absence) of diamond-indicator minerals. Consequently, this three-year project was initiated to provide the missing information. A similar effort (*Geochemical and Mineralogical Reconnaissance*) was carried out in southern Alberta by the Geological Survey of Canada, and both projects used the same sample-collection and analytical methods.

Methodology

The study area was that portion of Alberta north of 53°N and extending to the Alberta-Northwest Territories border. Some of the fieldwork and corehole drilling was carried out in concert with another Alberta Geological Survey project, namely *Surficial Geology Mapping and Quaternary Stratigraphy of the Peace River and High Level-Fort Vermilion Areas of Northern Alberta.*

Till samples were taken from 62 sites. Each sample was removed from below the top of the C soil horizon, generally at a depth of 1–2 m to minimize the effects of weathering on the carbonate content of the till and to maximize the preservation of indicator-mineral grains. Samples of approximately 25 kg were collected for indicator minerals, and 2–3 kg samples were taken for geochemical analysis. Also, stream-sediment samples were collected at three sites, and six coreholes were augered in the High Level-Fort Vermilion area.

Atomic Absorption and Neutron Activation analyses were carried out to determine the concentration of numerous elements. Approximately 100 samples were analyzed for elements, including diamond indicators.

Results

Geochemical analyses showed that high concentrations of some elements tend to be localized and appear to be related to the areas where the Shaftesbury Formation outcrops. Three sites having the highest concentrations of Co, Cr, Li, Zn, Sb, and V are located along a line passing through the NE corner of the Buffalo Head Hills, and the northern margin of the Birch Mountains.

G1 or G2 garnets and picroilmenites, which are strong indicators of diamonds, are rare in this area, but a few samples in the Peace River area contain G9 or G11 garnets and chrome diopsides, which might indicate peridotitic source rocks. More common are low-iron and high-magnesium G3 and G5 garnets. Based on experience from other diamond fields elsewhere in the world, these two minerals can indicate eclogitic source rocks. These types of rocks can be derived from rock formed within a diamond-stability field.

Although the distribution of diamond-indicator minerals was irregular, some trends appear to be evident. They are: (1) a southwesterly trend from an area immediately north of Peace River townsite to the Birch Hills northeast of Grande Prairie; (2) a southerly trend from the lower Wabasca River to the Loon River; and (3) a southwesterly trend in the area between Marguerite River and Fort MacKay.

Publications/Presentations

Dufresne, M.B., M.M. Fenton, J.G. Pawlowicz and R.J.H. Richardson. 1994a. Economic mineral potential of the Marguerite River and Fort MacKay area, northeastern Alberta (NTS 74E): preliminary report. Program and Abstracts. Third Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. February 10–11, 1994. Calgary, Alberta. p. 31.

Dufresne, M.B., M.M Fenton, J.G. Pawlowicz and R.J.H. Richardson. 1994b. Economic mineral potential of the Marguerite and Fort MacKay area, northeast Alberta (NTS 74E): preliminary studies. Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Annual General Meeting. May 2–4, 1994. Toronto, Ontario.

Dufresne, M.B., B.A. Henderson, M.M Fenton, J.G. Pawlowicz and R.J.H. Richardson. 1994. The mineral deposits potential of the Marguerite River and Fort MacKay areas, northeastern Alberta (NTS 74E). Alberta Research Council. Open File Report 1994-09. 67 pp., appendices.

Dufresne, M.B., R.A. Olson, M.M Fenton, J.G. Pawlowicz, W.A.D. Edwards, R.J.H. Richardson, D.R. Schmitt and B. McKinstry. 1994. The diamond potential of Alberta: a regional synthesis of the structural and stratigraphic setting and other preliminary indications of diamond potential. Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Annual General Meeting. May 2–4, 1994. Toronto, Ontario.

Dufresne, M.B., R.A. Olson, D.R. Schmitt, B. McKinstry, D.R. Eccles, M.M Fenton, J.G. Pawlowicz. W.A.D. Edwards and R.J.H. Richardson. 1995a. The diamond potential of Alberta: a regional synthesis of the structural and stratigraphic setting and other preliminary indications of diamond potential. Program and Abstracts. Fourth Annual Calgary Mining Forum. Calgary Mining Exploration Group Society. April 6–7, 1995. Calgary, Alberta.

Dufresne, M.B., R.A. Olson, D.R. Schmitt, B. McKinstry, D.R. Eccles, M.M Fenton, J.G. Pawlowicz. W.A.D. Edwards and R.J.H. Richardson. 1995b. The diamond potential of Alberta: a regional synthesis of the structural and stratigraphic setting and other preliminary indications of diamond potential. Abstracts. Current Activities Forum. Geological Survey of Canada. January 1995. Ottawa, Ontario.

Dufresne, M.B., R.A. Olson, D.R. Schmitt, B. McKinstry, D.R. Eccles, M.M Fenton, J.G. Pawlowicz. W.A.D. Edwards and R.J.H. Richardson. 1995c. The diamond potential of Alberta: a regional synthesis. Panel of Alberta Geological Survey display at the Prospectors and Developers Association of Canada Annual General Meeting. March 1995. Toronto, Ontario.

Dufresne, M.B., R.A. Olson, D.R. Schmitt, B. McKinstry, D.R. Eccles, M.M. Fenton, J.G. Pawlowicz, W.A.D. Edwards and R.J.H. Richardson. 1994. The diamond potential of Alberta: a regional synthesis of the structural and stratigraphic setting and other preliminary indications of diamond potential. Alberta Research Council. Open File Report 1994-10. 369 pp., appendices.

Fenton, M.M. and J.G. Pawlowicz. 1995a. Reconnaissance till mineral and geochemical survey, northern Alberta: Year 3. Program and Abstracts. Fourth Annual Calgary Mining Forum. Calgary Mining Exploration Group Society. April 6–7, 1995. Calgary, Alberta.

Fenton, M.M. and J.G. Pawlowicz. 1995b. Reconnaissance till mineral and geochemical survey, northern Alberta. Program and Abstracts. Fourth Annual Calgary Mining Forum. Calgary Mining Exploration Group Society. April 6–7, 1995. Calgary, Alberta.

Fenton, M.M. and J.G. Pawlowicz. 1995c. Reconnaissance till mineral and geochemical survey, northern Alberta. Year 3. Preliminary Report. Abstracts. Current Activities Forum. Geological Survey of Canada. January 1995. Ottawa, Ontario.

Fenton, M.M. and J.G. Pawlowicz. 1995d. Reconnaissance till mineral and geochemical survey, northern Alberta. Year 3. Abstracts. Geological Association of Canada Annual Meeting. Victoria, British Columbia. Vol. 20. p. A-31.

Fenton, M.M. and J.G. Pawlowicz. 1995e. Reconnaissance till mineral and geochemical survey, northern Alberta. Panel of Geological Survey of Canada display at the Prospectors and Developers Association of Canada Annual General Meeting. March 1995. Toronto, Ontario.

Fenton, M.M. and J.G. Pawlowicz. 1995f. Reconnaissance mineral and geochemical survey with emphasis on northeastern Alberta. Year 3. Alberta Geological Survey. Open File Report 1995-12. In press.

Fenton, M.M. and J.G. Pawlowicz. 1995g. Reconnaissance mineral and geochemical survey with emphasis on northern Alberta. Final Report. Alberta Geological Survey. Open File Report. In press.

Fenton, M.M. and J.G. Pawlowicz. 1995h. Preliminary stratigraphic tests to support mineral exploration: northern Alberta. Report for the end fiscal year 1994–95. Alberta Geological Survey. Open File Report 1995-11. 34 pp.

Fenton, M.M. and J.G. Pawlowicz. 1995i. Reconnaissance mineral and geochemical survey with emphasis on northern Alberta. Report for the end fiscal year 1994–1995. Till geochemistry northeastern Alberta. Alberta Geological Survey. Open File Report 1995-12. 26 pp., appendices.

Fenton, M.M. and J.G. Pawlowicz. 1994a. Reconnaissance till mineral and geochemical survey, northern Alberta. Year 2. Program with Abstracts. Geological Association of Canada Annual Meeting. Waterloo, Ontario. Vol. 19, p. A35.

Fenton, M.M. and J.G. Pawlowicz. 1994b. Reconnaissance till mineralogical and geochemical survey, northern Alberta. Year Two. Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Annual General Meeting. May 2–4, 1994. Toronto, Ontario.

Fenton, M.M. and J.G. Pawlowicz. 1994c. Year 2. Reconnaissance till mineral and geochemical survey, northern Alberta. Abstracts. Third Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. February 10–11, 1994. Calgary, Alberta. p. 59.

Fenton, M.M. and J.G. Pawlowicz. 1993a. Glacial geology of Alberta and implications for diamond exploration. Abstracts. Alberta Geological Survey Seminar "Diamonds in Alberta." February 1993. p. 8.

Fenton, M.M. and J.G. Pawlowicz. 1993b. Reconnaissance till mineral and geochemical survey, northern Alberta: results orientation survey. Abstracts. Geological Association of Canada Annual Meeting. Edmonton, Alberta. p. A30.

Fenton, M.M. and J.G. Pawlowicz. 1993c. Reconnaissance till mineral and geochemical survey, northern Alberta: preliminary results of orientation survey. *In:* Dunne, K.P.E. and B. Grant (eds). Mid-Continent Diamonds. Geological Association of Canada/Mineralogy Association of Canada Symposium. May 1993. Edmonton, Alberta. University of British Columbia. pp. 107–111.

Fenton, M.M. and J.G. Pawlowicz. 1993d. Surficial geology and Quaternary stratigraphy of the foothills, central and southern Alberta: a review. Abstracts. The Calgary Mining Forum. Calgary Mineral Exploration Group Society. March 3–4, 1993. Calgary, Alberta. p. 24.

Fenton, M.M. and J.G. Pawlowicz. 1993e. Till geochemistry and mineralogy, northern Alberta: preliminary report. Canadian Institute of Mining, Metallurgy and Petroleum Meeting. Calgary, Alberta. Bull. 86:986. p. 68.

Fenton, M.M. and J.G. Pawlowicz. 1993f. Reconnaissance mineral and geochemical survey with emphasis on northern Alberta. Report for the end of fiscal year 1992–93. Alberta Research Council Open File Report 1993-16. 16 pp., appendices.

Fenton, M.M., J.G. Pawlowicz and M.B. Dufresne. 1994. Reconnaissance mineral and geochemical survey with emphasis on northern Alberta. Report for the end fiscal year 1993–1994. Year 2 of a 3-year project. Alberta Research Council Open File Report 1994-21. 156 pp., appendices.

Study of the Geochemical and Stratigraphic Setting of the Shaftesbury and Associated Mid-Cretaceous Formations in Northern Alberta and Their Potential to Host Ore Deposits

Geological Survey of Canada (Calgary), APEX Geoscience Ltd. (Edmonton) and Alberta Geological Survey (Edmonton)

Project C1.35

Several important minerals and metals have been found in Shaftesbury Formation and other rocks of equivalent age in northern Alberta and Saskatchewan. Included are diamonds in kimberlitic pyroclastics, and base- and precious-metal bearing sulphidic horizons.

Furthermore, the geological setting of Shaftesbury Formation strata is consistent and correlative with many productive metalliferous districts of the world.

Consequently, the Geological Survey of Canada, in conjunction with APEX Geoscience Ltd. and the Alberta Geological Survey, undertook a field investigation in 1995 with the objective of evaluating the potential of the Shaftesbury Formation and associated sedimentary successions to host diamonds and base- and precious-metal deposits.

Specifically, the tasks were:

- identify stratigraphic and sedimentological controls on any potential mineral occurrences;
- to identify geological anomalies and target areas for mineral exploration;
- to identify exploration techniques for diamond, base-metal and precious-metal deposits that might be effective and suc cessful for industry; and
- to provide models for exploration in certain geologic and geographic domains based on selected criteria, such as ing and spatial distribution of local volcanism, and the rol of regional structural elements and the type of mineralization system present.

Results

Field work was carried out in the following areas: Peace River, Buffalo Head Hills, Birch Mountains and Caribou Mountains. All four areas contain Shaftesbury Formation rocks and others that are equivalent in age. Altogether, 557 samples were collected, and 79 sections were mapped stratigraphically.

At the close of the MDA program, laboratory analysis was being completed.

Publications/Presentations

Leckie, D.A., M.B. Dufresne and D.R. Eccles. 1996. Study of the geochemical and stratigraphic setting of the Shaftesbury and associated Mid-Cretaceous formations in northern Alberta and their potential to host ore deposits. Poster presentation at GSC Minerals Colloquium. January 1996. Ottawa, Ontario.

Preliminary Stratigraphic Test to Support Mineral Exploration in Northern Alberta

Geological Survey of Canada, Calgary

Project C1.34

definition of the chemical and mineralogical characteristics of the glacial till and supracrustal cover associated with Alberta diamondiferous kimberlite or lamproite diatremes would provide explorationists with useful information on the modes of kimberlite emplacement, timing and potential sedimentological factors which may have concentrated diamond r resources.

Little information of this type is available, however. Consequently, the objective of this project was to obtain infor mation on the stratigraphy, mineralogy and geochemistry of the glacial drift and the mineralogy and geochemistry of the bedrock associated with Alberta diatremes/kimberlites.

The project was carried out in cooperation with Alberta Geological Survey.

Methodology

The till and Cretaceous sediments that overlie kimberlite on the MONOPROS property near Grande Prairie were drilled

Results

At the close of the MDA program, litholog data were being prepared for release to the exploration community in 1996, while all additional data, including geochemical analyses, will be released in the future.

Surficial Geology Mapping and Quaternary Stratigraphy of the Peace River and High Level-Fort Vermilion Areas of Northern Alberta

Alberta Geological Survey and University of Alberta, Edmonton

Project M93-04-035

Active exploration for kimberlites, lamproites and other materials that indicate the presence of diamonds has shown that more geological information about parts of northern Alberta is urgently needed. Of particular interest are the surficial geology, the Quaternary stratigraphy and glacial history of two map areas: 83N W$^1/_2$ Winagami and 84C W$^1/_2$ Peace River. Therefore, the objective of this project was to supply this information.

Methodology

Reconnaissance surveys were made of surficial sediments and land forms; till samples were collected for analysis; borehole data were reviewed; and new boreholes were drilled (16 in the Peace River map area and 17 in the Winagami map area). Geochemical analysis was done on the collected samples using Atomic Absorption and Neutron Activation. Several samples were analyzed for diamond indicator mineralogy.

Results

The surficial geology and glacial stratigraphy of the Peace River map area suggest that the area was affected by one major ice advance. The presence of an unobstructed, southerly flowing Laurentide ice sheet is indicated by the surficial morainal deposits, flutes and morainal ridges in the uplands of the Clear and Whitemud hills. Deglaciation in the uplands is indicated by deposition from stagnant ice and erosion by meltwater channels that flowed downslope. In the lowlands, deglaciation caused the formation of glacial lakes surrounding the present-day towns of Peace River and Manning. The glacial stratigraphy is represented by a single glacial till. Terrace formation along the major rivers followed deglaciation.

The Quaternary geology and stratigraphy of the Winagami map area are consistent with at least one glacial episode. Apparently, the ice moved in two directions: a strong south-to-southwest movement; and a weaker southeasterly one. Most surficial deposits are associated with either ice stagnation and deglaciation or post-glacial processes. The area is covered extensively with glaciofluvial, glaciolacustrine, eolian and organic deposits.

Geochemical and mineralogical data are reported in the MDA project *Reconnaissance Till Mineral and Geochemical Survey and Quaternary Geology Project with Emphasis on Northern Alberta.*

Publications/Presentations

Balzer, S.A. 1995a. Glacial stratigraphy and dispersal patterns in the Winagami area (83N), northern Alberta. Conference Abstracts. CANQUA. 1995 Biennial Meeting. p. CA-2.

Balzer, S.A. 1995b. Quaternary geology Winagami area, northern Alberta. Program and Abstracts. CANQUA Annual Meeting. June 1995. St John's, Newfoundland.

Balzer, S.A. 1995c. Quaternary geology and stratigraphy of the Winagami area, northern Alberta (NTS 83N, western half). Program and Abstracts. Geological Association of Canada Annual Meeting. Victoria, British Columbia. Vol. 20. p. A4.

Balzer, S.A. 1994a. Preliminary surficial geology and drift stratigraphy of the Winagami area, northern Alberta. Program and Abstracts. Third Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. February 10–11, 1994. Calgary, Alberta. p. 57.

Balzer, S.A. 1994b. Preliminary surficial geology and subsurface stratigraphy of the Winagami area, northern Alberta. Conference Abstracts. Geological Association of Canada/Mineralogical Association of Canada Joint Annual Meeting. Victoria, British Columbia. Vol. 19, p. A6.

Balzer, S.A. and M.M. Fenton. 1995a. Preliminary Quaternary geology of the Winagami area, northern Alberta. Program and Abstracts. Fourth Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. April 6–7, 1995. Calgary, Alberta.

Balzer, S.A. and M.M. Fenton. 1995b. Quaternary geology and stratigraphy of the Winagami area, northern Alberta. (NTS 83N, western half). Final Report. Alberta Geological Survey. Open File Report. In prep.

Balzer, S.A., L.E. Leslie and M.M. Fenton. 1995. Quaternary stratigraphy and surficial geology, Peace River-Winagami region. Year Two report for the end fiscal year 1994–95. Alberta Geological Survey. Open File Report 1995-9. In prep.

Balzer, S.A., L.E. Leslie and M.M. Fenton. 1994. Quaternary stratigraphy and surficial geology Peace River-Winagami region. Report for the end fiscal year 1993–94. Alberta Research Council. Open File Report 1994-20. 32 pp., appendices.

Leslie, L.E. 1994. Preliminary surficial geology and drift stratigraphy of the Peace River area, northern Alberta. Program and Abstracts. Third Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. February 10–11, 1994. Calgary, Alberta. p. 62.

Leslie, L.E. and M.M. Fenton. 1995a. Preliminary Quaternary geology of the Peace River area, Alberta: Year 2. Program and Abstracts. Fourth Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. April 6–7, 1995. Calgary, Alberta.

Leslie, L.E. and M.M. Fenton. 1995b. Quaternary geology and stratigraphy of the Peace River area, northern Alberta (NTS 84C, western half). Final Report. Alberta Geological Survey. Open File Report. In prep.

Leslie, L.E., M.M. Fenton and J.G. Pawlowicz. 1994. Peace River region, Alberta; preliminary Quaternary stratigraphy and geology. Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Annual General Meeting. May 2–4, 1994. Toronto, Ontario.

Preliminary Stratigraphy Tests to Support Mineral Exploration: Northern Alberta

Alberta Geological Survey (Edmonton) and Geological Survey of Canada (Ottawa)

Project M94-04-039

The Alberta Geological Survey (AGS) and the Geological Survey of Canada (GSC) carried out separate, but coordinated, drilling programs in northern Alberta to obtain information that would be useful to other MDA projects.

Alberta Geological Survey Drilling Activities

The AGS undertook a short-term drilling program to provide support to two other projects: (1) *Geochemical and Stratigraphic Setting of the Shaftesbury Formation in Northern Alberta, and Its Potential to Host Ore Deposits*; and (2) *Reconnaissance Mineral and Geochemical Survey with Emphasis on Northern Alberta.*

The objective was to drill eight test holes in areas of moderately thick glacial drift to obtain core from both the drift and, if possible, the upper portion of the underlying bedrock. Sampling of these cores would lead to geologic and geochemical data being made available to the mineral exploration industry.

Methodology

The eight test holes were drilled at locations near Valleyview, Peace River and Red Earth. After the cores from each site were lithologged on site, they were sampled at Alberta Geological Survey laboratories and analyzed for geochemistry and diamond-indicator minerals.

Results

The detailed lithologs for each test hole are available and reported in the final report. The geochemical and other analysis results are included in the final report for the project, *Reconnaissance Mineral and Geochemical Survey with Emphasis on Northern Alberta.*

The project provided stratigraphic information in an area of Alberta where such information had not been previously obtained.

Planned Geological Survey of Canada Drilling Activities

The GSC drilling activities were related to a known kimberlite near Grande Prairie. At the close of the MDA program, drilling was scheduled to recover core from the drift and the upper portion of the underlying bedrock above and adjacent to the kimberlite. This should provide important information about the nature and origin of the kimberlite, as well as its geological setting and an indication of its diamond potential.

Meanwhile, GSC carried out an investigation concerning Shaftesbury Formation rocks.

Some rocks that were formed during the Late Cretaceous, and are now distributed around the world, have been found to host significant mineral deposits. In north-central Alberta, the Shaftesbury Formation represents rocks of this age and geological setting, which are characterized by coeval volcanism and faults or fractures that transect either the basement or overlying Phanerozoic rocks. Thus, Shaftesbury Formation rocks could host selected types of ores, and this portion of the project was undertaken to provide a detailed geological and geochemical assessment of that potential.

In particular, information was gathered concerning the formation's potential for hosting diamondiferous pyroclastics and diatremes, stratiform lead-zinc or nickel-zinc plus precious metal shales, gold deposits in disseminated sediments, and volcanogenic sulphide deposits.

In cooperation with Alberta Geological Survey, the services of APEX Geosciences Ltd. of Edmonton were contracted to conduct a field study in 1995. The principal objectives of the study were:

- to identify favourable geological anomalies and target areas for mineral exploration in, or spatially associated with, Shaftesbury Formation sedimentary rocks;
- to identify exploration techniques for diamond, base-metal and precious-metal deposits that might be effective and successful for industry to use in northern Alberta; and
- to provide models for exploration in certain geologic and geographic domains based on selected criteria, such as timing and spatial distribution of local volcanism, the role of regional structural elements (Peace River Arch, Great Slave Lake Shear Zone and the Steen River Structure) and the types of mineralized systems that are present.

At the close of the MDA program, the field work had been completed and data interpretation was under way.

Assessment of the Potential of Co-product Minerals and Metals in Alberta Oil Sands Deposits

Gulf Canada Resources Limited, Calgary

Project M92-04-004

Previous investigations have indicated that many types of metals and minerals are present in the oil sands of northern Alberta. Their concentrations, however, are probably too low to justify building extraction operations for the sole purpose of recovering them. At the same time, making synthetic crude oil from oil sand bitumen continues to be relatively expensive, even though extraction and production costs have declined sharply over the past 10 years. One way to improve the economics of bitumen recovery might be to combine it with operations that recover co-product metals and minerals from the same deposits. Consequently, this study was undertaken to investigate the concept. It was intended to be the first phase of a larger study.

The objectives of this first-phase study were to determine the concentration and distribution of potential co-product minerals and metals present in the Athabasca oil sand deposit.

The project was divided into five tasks. They were:

- for purposes of sampling, select a representative site which could serve as the basis for later studies and whose geology was well documented;
- examine the co-product potential in the cores from two holes drilled at this site;
- develop procedures for removing samples from these cores that represent all geological facies present in the deposit;
- develop procedures for analyzing the principal elements present in each facies and identify any relationships among them or with the solid, bitumen and organic phases of the core samples; and
- determine whether the elements can be extracted with strong acid.

Study Methodology and Results

Two cores from the Sandalta oil sand lease (40 km north of Fort McMurray) were selected for analysis. These cores had been obtained in 1985. One core contained a section of oil-rich sand, while the other contained a section of lower-grade oil sand and waste. Both represented the principal geological facies found in this deposit.

Also, some tailings samples were analyzed. They were from a pilot plant operation that was used to extract aluminum from tailings material.

Methods for removing samples from each facies were investigated, and procedures were adopted to avoid problems, such as invasion by drilling mud and contamination by cutting tools.

Two hundred samples were extracted from the two cores. These samples were then analyzed for 55 elements using three techniques: (1) Induced Neutron Activation Analysis (INAA), (2) Inductively Coupled Plasma (ICP), and (3) Fire Assay. Each technique had certain strengths, but INAA was used in most instances. Altogether, more than 10 000 analyses were performed, using the services of three analytical laboratories.

It was found that the concentration of elements ranged from one part per billion to 500 parts per billion. All 10 000 analysis results are available on a floppy disk in Excel 4.0 format.

The analysis data were then subjected to statistical interpretations. Concentration ranges and statistical averages for each element and each facies were determined, and the plots of all these data are included in the project report.

Principal Observations

It was found that the depositional environments which existed when the formations were developing are an excellent sorting mechanism for elements, and geological facies reflect these various depositional environments. Thus, there was a strong correlation between facies and the elements likely to be present in each. For example, those facies that represented high-energy depositional environments tended to be coarse grained, have high bitumen and silica contents, and have low concentrations of most other elements. Examples of high-energy environments include fluvial channels, fluvial estuaries, interchannels, tidal channels and lower tidal flats.

Depositional environment	Facies	Sub facies	Gross lithology	% of total	Typical % bitumen
Estuarine	Pro Delta Mud		Silt and Clay	4.0%	0–3%
	Salt Marsh		Clay	3.7%	0–3%
	Abandoned Channel		Sand, Silt and Mud		1–14%
	Inter Channel		Sand with some Silt and Clay	14.2%	12–16%
	Tidal Channel	Tidal Channel	Sand	17.0%	13–16%
		Tidal Channel with Breccia	Sand with silt and clay breccia	0.3%	6–14%
	Channel Breccia		Clay clasts in sand	0.2%	2–16%
	Upper Tidal Flat	Burrowed	Silt and Sand	10.7%	1–7%
		Bedded (layered)	Silt and Sand	1.8%	3–13%
		Burrowed and Bedded	Sand and Silt	10.8%	2–9%
	Lower Tidal Flat	Burrowed	Sand and Silt	4.5%	5–11%
		Bedded (layered)	Sand and Silt	5.8%	9–15%
		Burrowed and Bedded	Sand and Silt	5.8%	5–13%
		Tidal Mud	Clay	0.1%	5–13%
Coastal Plain	Fluvial Estuarine		Sand	0.9%	11–16%
	Delta Marsh Mud		Clay	0 5%	0–1%
	Overbank Mud		Silt and Clay	1.0%	0–13%
	Crevasse Splay		Sand, Mud Debris	1.2%	0–4%
	Coal		Coal	0.4%	0%
	Fluvial Channel	Oil-Bearing	Sand	10.7%	8–17%
		Water-Bearing	Sand	1.1%	1–7%
		Mixed oil and water	Sand	1.7%	1–11%
		Fluvial Channel Breccia	Sand and Breccia	0.5%	6–14%
	Fluvial Breccia		Clay Clasts in Sand	0.1%	Not present
	Abandoned Channel		Sand, Silt Mud	0.3%	1–14%

Geological facies present at the Sandalta site

Contrasting this were facies that formed in low-energy depositional environments. They tended to be fine grained, have low bitumen and silica contents, and have higher concentrations of other elements.

Examples of this type of depositional environment, which are characterized by still-water conditions, include delta marsh mud, overbank mud, pro delta mud and salt marshes.

The concentration of titanium and zirconium appears to increase significantly in fine-grained facies. It was noted that the concentration of these minerals in recoverable heavy-mineral fractions may be much lower than was previously believed.

The concentration of nickel and vanadium also increased in fine-grained materials. This is significant because it has been suspected that the presence of these minerals is positively linked to that of bitumen, but the analysis results from this study suggest the opposite relationship.

Another relationship was detected. It appears that aluminum content is directly related to the amount of clay-sized material, defined as material finer than two microns in size. Also, a similar direct relationship exists between aluminum and other elements: as aluminum content rises, so does that of most other elements. Silica and cobalt are exceptions to this trend.

A useful predictive relationship was also found. Gamma count is directly related to the amount of clay-sized material, the amount of aluminum and other elements concentrated in fine-grained materials, and the Methylene Blue Index, which also indicates the amount of clay-sized material.

It was suggested that gamma logs of core samples could be used to predict the following:

- clay content;
- potential bitumen content of the oil sand;
- the processing characteristics of the oil sand feed;
- the quantity of materials likely to form sludge; and
- the quantity of fine tailings likely to be produced.

Usually, the concentration of precious metals was only a few parts per billion (ppb), but in some samples it ranged as

high as 77 ppb. The number of cores used in this study was inadequate to demonstrate conclusively that placer deposits of precious metals were either absent or present.

Analysis of the tailings samples showed that a low-grade ore contained more aluminum and associated elements than did a high-grade ore, and fine tailings contained the highest concentrations of aluminum and other elements. Also, acid leaching at this pilot plant selectively removed aluminum, chlorine and iron from fine tailings.

Publication

Devenny, D.W. 1993. A Study to Assess the Potential of Co-Product Minerals and Metals in Alberta's Oil Sand Deposits. Phase I. Gulf Canada Resources Limited. 25 pp., appendices, computer disk.

Commodity Profiling of Principal Industrial and Metallic Minerals in Alberta

Alberta Geological Survey, Edmonton

Project M92-04-015

Thirty non-hydrocarbon minerals that exist in Alberta are being exploited or could be exploited, and another dozen or so might have some potential for commercial extraction. Collectively, these minerals are the basis of Alberta's secondary mineral-development industry.

One way to interest industry explorationists in a mineral is to provide them with a commodity profile, which is a summary of its resource status. These profiles provide entrepreneurs with a geological, technical and economic background that helps them identify commercial opportunities and make mineral-property assessments. The Alberta Geological Survey has prepared such profiles in the past on limestone, gold, sodium sulphate, lead-zinc, silica, gypsum, phosphate, dimension stone, platinum group elements and zirconium. These profiles have been well received by industry, and the objective of this project was to continue the effort.

Methodology

As in the past, available information was assembled in a standardized format according to the following headings:

- Industry Setting;
- Geology and Resources;
- Mining/Mineral Technology;
- Economic Factors;
- Industry Operating Factors;
- Strategic Considerations; and
- Outlook.

Results

Commodity profiles were produced for two minerals: bentonite and crushed stone. Data that were gathered on magnetite will be released later and four previously released profiles on dimension stone, gypsum, phosphate and silica were re-issued as a single reprint collection within the current series.

Bentonite

Numerous undeveloped deposits of bentonite are known to exist in Alberta, and the mineral was mined at two locations in the past. It is considered to be an important material for applications involving certain specialty products. The commodity profile focuses on these market opportunities.

Magnetite

When the commodity-profiling work began on this mineral, it promised to be the first metallic mineral to be mined in Alberta, since plans were under way to use it for heavy-medium coal washing. The mine, however, did not proceed, and another proposed development was delayed. Consequently, the commodity profile was deferred. Meanwhile, all information on magnetite will be combined with that of other iron-bearing minerals and released in 1996.

Crushed Stone

Most crushed stone is used in Alberta as decorative stone or specialty aggregate. Some promising market potential is discussed in the commodity profile for this material.

Publications

Alberta Research Council. 1994. Broken and Crushed Stone: Alberta Mineral Commodity Profile. Alberta Research Council. Open File Report 1994-03. 19 pp. In press.

Godfrey, J.D., W.N. Hamilton and D.E. Macdonald. 1993. Dimension Stone, Gypsum, Phosphate, Silica: Alberta Mineral Commodity Profiles (reprint volume). Alberta Research Council. Open File Report 1993-05. 91 pp.

Master, P.P. 1993a. Bentonite — a mineral profile (an MDA-sponsored program). 95th Annual General Meeting and 44th Annual Technical Meeting of the Canadian Institute of Mining, Metallurgy and Petroleum. Calgary, Alberta. May 9–12, 1993.

Master, P.P. 1993b. Bentonite: Alberta Mineral Commodity Profile. Alberta Research Council. Open File Report 1993-06. 57 pp.

Regional Synthesis and Characterization of Industrial Limestones in Alberta

Alberta Geological Survey, Edmonton

Project M92-04-014

Limestone is one of Alberta's most valuable non-energy minerals. Cement and lime made from it are worth more than $150 million annually. Although extensive deposits of limestone are found in Alberta, those that can be exploited are limited. This is compounded by dwindling supplies and rising demand, which add urgency to the need to find new supplies. Thus, the objective of this project was to conduct comprehensive resource analyses of limestones in Alberta.

Methodology

All data on limestones from previous studies were consolidated, and field investigations were carried out to supplement this information. These investigations included evaluation of limestone potential at particular locations. This involved a geological survey to assess the economics of recovering the rock, particularly by quarrying, as well as the extent and quality of the reserves. In addition, samples were analyzed for chemical composition, brightness and ability to be ground and calcined. Some limestone samples were assayed for indications of their ability to host metalliferous deposits.

Initially, field investigations during this three-year project were carried out in the David Thompson and Yellowhead mountain corridors. In these areas, several previously untested sites in Paleozoic carbonate formations were investigated and sampled. This work was followed by investigation in the northeast Plains. Detailed surface and subsurface mapping of Devonian carbonate successions was carried out, and Devonian outcrops along the principal rivers were mapped and the main limestone units were sampled. Finally, some investigations were made of the disturbed belt outside the main mountain corridors between the North Saskatchewan River and Crowsnest Pass, and some sites within the Crowsnest Pass were examined.

Results

At least one new location in the Yellowhead corridor and several in the David Thompson corridor show some promise as potential sources of industrial limestone.

The Yellowhead prospect is in the core of the Folding Mountain anticline, in the Devonian Palliser Formation, and a full evaluation would require test drilling.

In the David Thompson corridor, limestones occur at Windy Point (Cambrian Eldon Formation), west of Windy Point (Devonian Fairholme Group and Palliser Formation strata), at Cline River Junction (Palliser Formation), and at several locations between Cline River and Whirlpool Point. Excepting the Eldon Formation, the main carbonate units in the massive Cambrian succession dominantly comprise dolomites. Also, the major exposures of Cambrian carbonates are not readily accessible in the corridor.

Investigation of Paleozoic formations in the Crowsnest corridor failed to locate any new limestone prospects, and those found between this corridor and the North Saskatchewan River have limited potential. One exception is a deposit at Prairie Creek near Strachan. It lies near a gas processing plant, which is also the site of a proposed cement plant.

Some good-quality limestones are found within the Moberly Member of the Waterways Formation in northeast Alberta. Most would need to be extracted by underground mining, however.

Gold and metal alloys were found in limestones from this region, but in minute quantities.

Publications

Cotterill, D.K. and W.N. Hamilton. 1995. Geology of Devonian Limestones in Northeast Alberta. Alberta Research Council Open File Report 1995-07. 38 pp., appendices and maps.

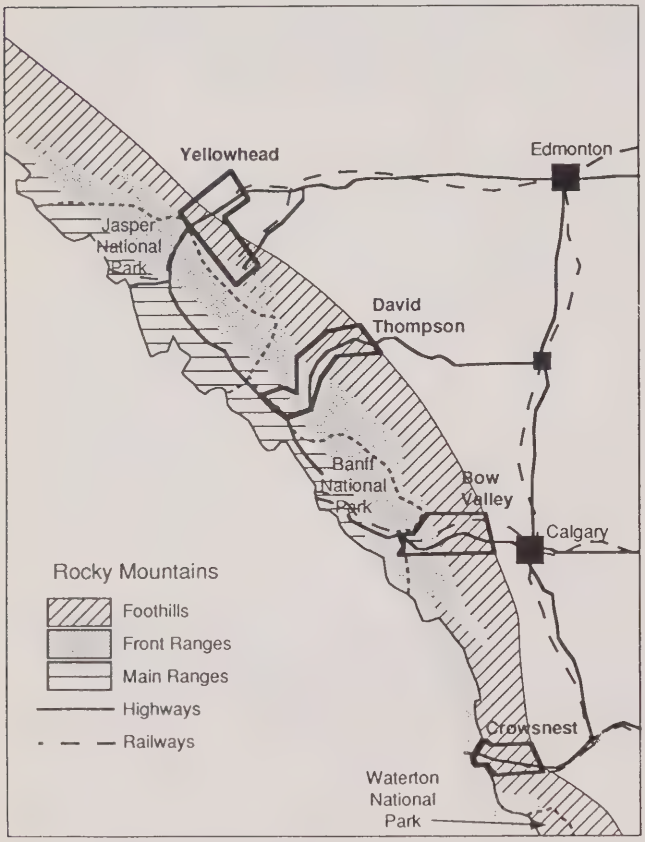
Mineral Resource Mapping of Main Mountain Corridors

Alberta Geological Survey, Edmonton

Project M92-04-013

No matter where mountains are found, access to them and through them is difficult, except in passes or corridors. Here, rivers often flow, roads and railways are often built, and settlements sometimes arise. People who frequent these corridors are able to observe and exploit any mineral occurrences that are present, and if a transportation infrastructure exists, this is an added advantage.

In Alberta's case, the mountain corridors have revealed industrial minerals, such as limestone, clay and shale, sandstone, aggregate, quartzite, phosphate rock, magnesite and talc, as well as some metallic minerals. Despite these discoveries and relatively easy access, Alberta's mountain corridors have not been well mapped for mineral occurrences. Furthermore, these corridors are believed to host some of the minerals that are required by newer industries, such as pulp and paper. Thus, the principal objective of this project was to map the mineral resources of three main mountain corridors in Alberta, namely Crowsnest, David Thompson and Yellowhead.



Location of the four main mountain corridors of interest. The Bow Valley corridor study was completed prior to the start of the MDA program.

Methodology

All existing information on the geology and mineral deposits in the three mountain corridors was assembled, and field investigations were carried out to fill the gaps in knowledge. More than 300 samples collected during the first three years of this four-year project were analyzed for chemical, geochemical, petrographic and other characteristics. All data are presented on maps.

Results

Except for magnetite in the Crowsnest corridor, no metallic minerals were found in any of the corridors.

Approximately 35 sites in the David Thompson corridor were investigated for industrial minerals between Nordegg and Banff National Park gate. Several sites are promising for limestone, dolomite and other industrial minerals. Since the David Thompson corridor is the only accessible part of the disturbed belt outside the mountain parks where one might find metallic minerals in Lower Paleozoic and Precambrian rocks of the Main Ranges, a stream-sediment geochemical survey was carried out in the Cline River drainage basin. Altogether, 48 stream-sediment samples were collected and analyzed. At least two gold anomalies and two zinc anomalies were found. In addition, gossaniferous zones observed on mountainsides and a malachite stain found at one location suggest the potential for metallic minerals.

In the Crowsnest corridor, several new industrial mineral sites were described and sampled. Ceramic clay, dimension stone and magnetite were found in Cretaceous rocks. Clay rocks are common in this corridor, and the sites tested in this project for the first time are well-located for development. Some agglomerates and tuffs in the Crowsnest Volcanics and massive sandstone beds in the Blairmore, Belly River and St. Mary River formations all show promise for recovery of building stone or dimension stone. The magnetite, which occurs in paleoplacer deposits in a sandstone unit at the base of the Belly River Formation, is suitable as a heavy medium for coal washing.

Approximately 20 sites in the Yellowhead corridor were investigated and sampled. All were between Obed Mountain and Jasper National Park gate. One new prospect for limestone was found. It is in the Devonian Palliser Formation. Also, several clay and shale localities are promising for recovery of ceramic clay.

Maps of the three corridors were prepared at a scale of 1:100 000.

Publication

Hamilton, W.N., M.C. Price and D.K. Chao. 1996. Mineral resource mapping of the main mountain corridors. Alberta Geological Survey Open File Report 1995-3. 6 maps. In prep.

Mineral Aggregate Commodity Analysis

Alberta Geological Survey, Edmonton

Project M93-04-036

Mineral aggregate resources in Alberta are being consumed twice as fast as new ones are being found. Those that are known are under pressure from competing land uses. Some have been made inaccessible because infrastructure has been built on them, while others have lost out to competing forces, and access to them has now been denied. Much information about the extent of reserves is confidential, owing to a lack of public accounting of reserves, the absence of a broad initiative to generate data, and no coordination of existing information.

This project was undertaken to help overcome some of these deficiencies.

The objectives of the project were:

- to evaluate existing data sources for mineral aggregate in Alberta and select the most effective for gathering 1991 data;
- to establish the amount of mineral aggregate consumed or produced by region;
- to identify market regions;
- to determine regional costs and commodity transport distances;
- to assess the perception of resource availability for both sand and gravel;
- to determine the types of environmental or legislative activities that affect mineral aggregate development;
- to determine the types of mineral aggregate development which have environmental, economic or quality-of-life effects on the public; and
- to prepare a comprehensive report on mineral aggregate resource use in Alberta at the regional scale.

Methodology

Questionnaires were sent to the three types of aggregate producers: (1) Counties, Municipal Districts and Improvement Districts; (2) cities, towns and railways; and (3) private operators and landowners/operators.

The information received in response to these questionnaires was analyzed according to the following categories: volume of sand production per region; volume of gravel production per region; value of sand production per region; value of gravel production per region; average per capita cost of sand per region; average per capita cost of gravel per region; and maximum haul distance per region.

In addition, the following information was summarized and interpreted: the expected lifetime of sand supplies per region; the expected lifetime of gravel supplies per region; the activities restricting aggregate development per region; and the activities of aggregate development which affected the environment or quality of life.

Results

The mineral aggregate industry comprises several thousand pits operated by approximately 300 producers. Annual production exceeds 45 million tonnes, making Alberta fourth in total production in Canada and second in the production of sand and gravel.

Mineral aggregate used in Alberta is almost entirely produced from unconsolidated sand and gravel deposits. These deposits can be divided into the following geological types: preglacial; glaciofluvial (outwash and ice-contact); alluvial; glaciolacustrine; eolian and colluvial. Geological models have been developed for most types of deposits and information is available to aid explorationists in finding deposits.

Publicly available information about known reserves, however, is sparse since it is regarded as confidential by operators and Alberta Transportation and Utilities. Nonetheless, the survey revealed that half of all municipal regions in Alberta will be depleted of known gravel supplies within 20 years.

Most sand and gravel (69 per cent) is used in road construction and maintenance, while 11 per cent is used for concrete in construction, and 7 per cent is used in asphalt. Total Alberta production of sand and gravel in 1991 was valued at approximately \$153 million, with an average per tonne cost of \$3.37.

Approximately half the total production is consumed in Calgary and Edmonton, but the highest per capita consumption occurs in those regions of the province having the lowest population.

Land use concerns are becoming a significant aspect of sand and gravel extraction. Almost one-third of public and private sector operators who responded to the 1991 survey claimed their efforts to mine a deposit were either curtailed or prevented by land use or environmental restrictions. The key issues appear to be:

- conflict between the needs of operators to develop pits near markets, and the desire of people who live near pits to maintain their quality of life;
- the desire of operators to maximize recovery from deposits, and the desire of governments to protect natural areas, particularly water courses; and

- the concern of all parties about the nature and enforcement of laws and regulations.

Conclusions

The current knowledge of resource location and reserves is declining. No public mapping has taken place for at least five years, but some resources have since become depleted while others have been removed from access through land-use restrictions. More attention has been paid to development restriction than to resource conservation or resource accounting.

There is a need to define resource market areas, to provide land management within these market areas, to provide inventories of the resource, and to prepare more maps in greater detail.

Unlike other areas of North America, where the mineral aggregate sector is regarded as mature, Alberta's is not. What is missing is a system that is supported by baseline data on the resource, and consistent procedures and controls for dealing with environmental and public concerns, while sustaining production. Since the resource is declining, but is in greater demand, these issues must be resolved within 10 years.

Publication

Edwards, W.A.D. 1995. Mineral Aggregate Commodity Analysis. Alberta Geological Survey. Open File Report 1995-08. 54 pp., maps and tables.

Evaluation of the Potential for Recovery of Industrial Minerals from Alberta Brines

Alberta Geological Survey, Edmonton

Project M92-04-011

Formation waters have been a source of industrial minerals for ages, and are used in Alberta to supply some commercial mineral-extraction operations.

In the past, some studies have been done in Alberta concerning individual dissolved minerals, but this project had a broader scope: to determine areas and stratigraphic intervals in the sedimentary succession in Alberta that contain economically significant industrial minerals dissolved in formation waters. The minerals of interest were calcium (Ca), magnesium (Mg), potassium (K), lithium (Li), iodine (I) and bromine (Br).

Methodology

Unlike ore bodies, which are discontinuous within their host rocks, formation waters are geochemically continuous. This difference alters the manner of assessing dissolved minerals. In this case, regional and exploration values were defined for each element based on existing fields where it is being produced economically. Most of these fields are in Michigan.

Since the 1930s, information on formation waters has been available in Alberta from wells drilled during petroleum exploration. In addition, similar information has been gathered over the years by the Alberta Geological Survey. Altogether, a database containing 130 000 analyses of formation waters was searched for information on the contents of Ca, Mg, K, Li, I and Br. Specifically, the data of interest were those where the mineral contents exceeded the following values: 60 000 mg/L for Ca; 9 000 mg/L for Mg; 10 000 mg/L for K; 75 mg/L for Li, 100 mg/L for I and 3 000 mg/L for Br.

Using information from well logs, drillstem tests and core analyses, areas were identified in target stratigraphic intervals which met the concentration criteria and the following requirements: interval thickness >10 m; porosity >5 per cent; and permeability $>10^{-14}$ m^2, 10 millidarcies. Resources, expressed in the amount of element per unit surface area of the respective stratigraphic interval, were estimated for the identified areas and strata.

Results

Calcium, magnesium and potassium concentrations exceed the designated threshold in Devonian Elk Point Group strata in central Alberta and in Beaverhill Lake Group strata in southern Alberta. Bromine is also present in high concentrations. Devonian Beaverhill Lake and Woodbend strata in west-central Alberta contain formation waters having lithium concentrations above the threshold. Also, formation waters in the Cretaceous Viking and Belly River strata in south-central Alberta contain iodine in concentrations that approach the threshold, but they are discontinuous over large areas.

Lower Elk Point Group strata (at depths between 1 650 and 2 040 m) in two areas of central Alberta contain formation waters having high concentrations of Ca, Mg, K and Br. Analysis indicated concentrations of 25–180 kg/m^2 for Ca, 2–32 kg/m^2 for Mg, up to 2.4 kg/m^2 for K and up to 2 kg/m^2 for Br.

Of even greater economic significance are Beaverhill Lake Group strata in six areas of southern Alberta. Here, at depths varying from 1 240 m in the east to 2 600 m in the west, the concentrations of elements are: 50–760 kg/m^2 for Ca; 4–136 kg/m^2 for Mg; up to 116 kg/m^2 for K; and up to 10 kg/m^2 for Br.

Lithium in high concentrations is found in formation waters of the Woodbend and Beaverhill Lake groups in west-central Alberta. These platform and reefal carbonate hosts are between 2 700 and 4 000 m deep. Lithium concentrations vary between 0.01 and 0.57 kg/m^2.

In localized areas within Viking and Belly River strata in south-central Alberta, iodine concentrations of some significance are found at depths between 650 and 950 m. In the Viking strata, the concentrations are 0.2–1.8 kg/m^2 and 0.3–1 kg/m^2 in the Belly River strata.

Full details are found in the project final report.

Publication

Hitchon, B., S. Bachu, J.R. Underschultz and L.P. Yuan. 1995. Industrial Mineral Potential of Alberta Formation Waters. Bulletin No. 62. Alberta Geological Survey. 64 pp.

Hitchon, B., J.R. Underschultz and S. Bachu. 1993. Regional distribution of potential mineral resources in Alberta formation waters. 95th Annual General Meeting and 44th Annual Technical Meeting of the Canadian Institute of Mining, Metallurgy and Petroleum. May 9–12, 1993. Calgary, Alberta.

Brine Resources of Alberta

Geological Survey of Canada, Calgary

Project C1.41

Concurrently with a study carried out by the Alberta Geological Survey to investigate the character and distribution of the brine resources of Alberta, the Geological Survey of Canada began a complementary study of the origin of brines in central Alberta. Meanwhile, mineral exploration by private companies resulted in the surprising discovery of a new type of precious-metal mineralization in the Fort MacKay area of northeastern Alberta. This new type of mineralization was judged sufficiently important to future mineral development in Alberta that the focus of this project was changed so that more could be learned about this new type of mineralization.

The objective of the original study was to characterize the mineralogy and origins of evaporite rocks in Alberta which contain highly saline evaporite brines that have potential for industrial use. Much of the required information is on file in the digital water-analysis database at the Geological Survey of Canada in Calgary.

When the occurrence of precious-metal mineralization was discovered in Devonian limestone near Fort MacKay, samples were examined and found to contain novel mineralization in Precambrian and Phanerozoic rocks. This has been called "Prairie-type" mineralization because it appears that oxidized, chloride-rich brines from the Prairie Formation played a part in mobilizing and transporting metals, including gold, silver and copper.

Further investigation of this mineralization process was warranted, and the objectives of this sub-project became as follows:

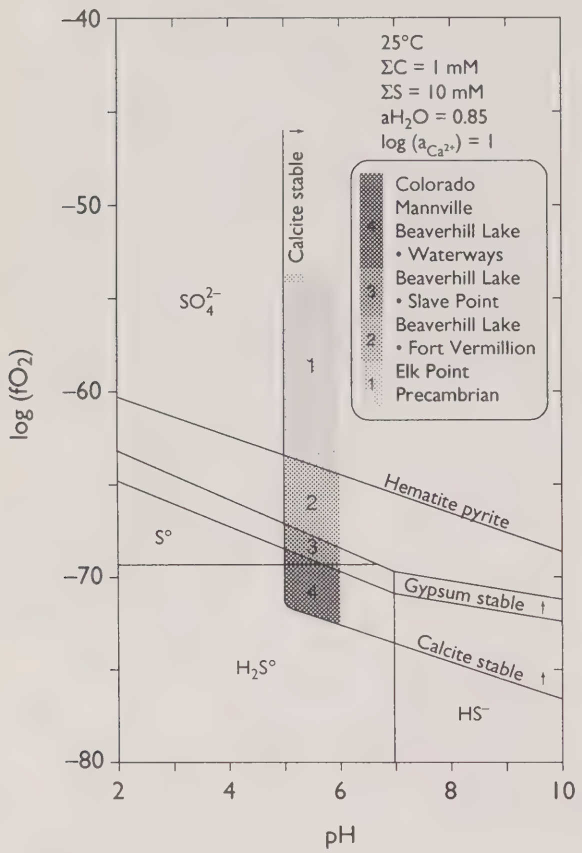
- to document the mineralogy and distribution of Prairie-type mineralization;
- to investigate relations between mineralization and alteration of basement and Phanerozoic sedimentary rocks;
- to document regional brine chemistry in northeastern Alberta and investigate the extent to which this may correlate with alteration and mineralization that is preserved in basement and sedimentary rocks;
- to map the regional surface and subsurface geology of northeastern Alberta, documenting the thicknesses and attitudes of major formations and the Precambrian surface;
- to map possible structures using regional geology and available aeromagnetic and gravity data; and
- to produce a regional synthesis of all available geological, mineralogical and geochemical data.

Methodology

Field investigations were carried out in 1994 and 1995. They included a major river-water sampling program along the Athabasca River from Fort McMurray to Bitumount, which was supplemented by samples taken along and near major roads. This was followed by geological mapping and sampling of the Beaver River sandstone, which is an unusual quartz-cemented, diagenetic lithofacies of the lower member of the Lower Cretaceous McMurray Formation. Two companies — Lac Minerals Ltd. and Birch Mountain Minerals Ltd. — provided access to additional cores that were drilled near Fort MacKay. Also participating in this investigation were the Alberta Geological Survey, Focal Resources Ltd., NSR Resources Ltd. and Tintina Mines Ltd.

Optical and scanning-electron microscopy were used to examine samples of core and surface materials and determine the extent of mineralization and alteration, as well as relations among mineralized, altered and unaltered lithologies. Geochemical analyses were performed on surface samples and core samples supplied by industry. These analyses involved solution and laser-ablation Inductively Coupled Plasma-Mass Spectro-

metry (ICP-MS) techniques. Surface water and subsurface water data were used to prepare regional composition maps for major formations.



pH vs logarithm of oxygen fugacity for northeastern Alberta. Shading indicates the relation between pH-redox and stratigraphy (modified from Abercrombie and Feng, 1996).

Results

The Prairie-type mineralization discovered near Fort MacKay consists of microdisseminated native and intergrown or alloyed metals and phases of metal oxide, metal chloride, metal carbonate and minor amounts of metal sulphide. It is believed it originated with oxidized, highly saline brines derived from halite evaporites of the Prairie Formation of the Middle Devonian, Elk Point Group. These brines were first driven downward by density into red bed evaporite sequences and the fractured Precambrian basement, and then migrated upward and discharged at the eastern, up-dip edge of the basin.

The lower section of the stratigraphic column has undergone some oxidation and comprises uppermost Precambrian basement plus red beds, dolostone and evaporites of the Middle Devonian Elk Point Group and the lower part of the Upper Devonian Beaverhill Lake Group.

The upper part of the succession is relatively reducing in character. It comprises silty limestone of the Beaverhill Lake Group and bitumen-saturated tar sands and barren siltstone of the Lower Cretaceous Mannville Group. Native sulphur is found at the interface of the upper and lower sections.

Beaver River sandstone (BRS) occurs in the upper section. It is moderately to intensely cemented, and was used in the past by aboriginal people to make stone projectile points. BRS contains microdisseminated gold and associated base-metal mineralization. Further studies of BRS were under way at the close of the MDA program.

Geochemical analyses by solution chemistry found 130 parts per billion (ppb) of gold in a sample of Devonian Waterways Formation limestone, but laser-ablation ICP-MS found 1.6 parts per million (ppm) in a similar sample. The latter technique also found 1.08 ppm of gold in a sample of BRS, and it found gold in the residues left from the solution technique. The inconsistencies of the two assay methods are another aspect of the project to be further investigated.

The discovery of novel microdisseminated mineralization near Fort MacKay provides new opportunities for research into mechanisms of metal transport and deposition in geological environments previously believed to be unpromising. Since the initial discovery, several companies have spent approximately $7 million conducting additional exploration in the Fort MacKay area.

Publications/Presentations

Abercrombie, H.J. 1995. Geochemistry and petrology of Prairie-type Au-Ag-Cu mineralization, Fort MacKay, Alberta. Program and Abstracts. Fourth Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. April 6–7, 1995.

Abercrombie, H.J. and R. Feng. 1996. Geology of Prairie-type Au-Ag-Cu mineralization, Fort MacKay region, northeastern Alberta. Geological Survey of Canada Bulletin (R.W. Macqueen, editor). In press.

Abercrombie, H.J. and R. Feng. 1995. "Prairie-type" brine-associated Au-Ag-Cu mineralization in the Western Canada Sedimentary Basin. Geological Survey of Canada, Mineral Forum 1995 Abstracts. p. 3.

Abercrombie, H.J. and R. Feng. 1994a. Gold and PGE anomalies in Phanerozoic sedimentary rocks, northeastern Alberta — potential for new deposits? Program and Abstracts. Third Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. February 10–11, 1994. p. 51.

Abercrombie, H.J. and R. Feng. 1994b. Prairie-type disseminated gold-silver-copper mineralization in the Western Canada Sedimentary Basin: brine-associated native and alloyed metals, chlorides, oxides and carbonates. 1994 Annual Meeting. Geological Society of America. Abstracts with Program. 26:7. p. A-83.

Ballantyne, S.B. and D.C. Harris. 1996. Alluvial platinum group minerals and gold in Alberta: results from the "Orientation Studies Project" and their exploration significance. Final Report. Alberta Mineral Development Agreement. Geological Survey of Canada Bulletin. In review.

Feng, R. and H.J. Abercrombie. 1994a. Disseminated Au-Ag-Cu mineralization in the Western Canada Sedimentary Basin, Fort MacKay, northeast Alberta. International Association for the Geology of Ore Deposits. Beijing, China. *Also*: Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Annual General Meeting. May 2–4, 1994. Toronto, Ontario.

Feng, R. and H.J. Abercrombie. 1994b. Disseminated Au-Ag-Cu mineralization in the Western Canada Sedimentary Basin, Fort MacKay, northeast Alberta: a new gold deposit type. Current Research 1994-E. Geological Survey of Canada. pp. 121–132.

McDonough, M.R. and H.J. Abercrombie. 1995. Mineral occurrences in Middle Devonian carbonates, Salt River and Stony Islands (Slave River) areas, northeastern Alberta. Current Research 1995-B. Geological Survey of Canada. pp. 125–130.

Mineral Information System

Alberta Geological Survey, Edmonton

Project M92-04-005

Having supported more than 30 geoscience research projects, the MDA program generated a considerable volume of new information. While it is possible to access and read the project reports, this is a time-consuming way to obtain needed information. An alternative is offered by this project, which created a computerized information system that assimilates, stores and makes accessible all the geoscience information generated by the MDA program.

Methodology and Results

Taking into account the need for having very basic processes that can be used to query the database and display retrieved information, a mineral information system (MIS) was designed. It is based on the Ingres relational data base management system and operates as an application within Windows4GL, which is a graphical user interface to Ingres. Another part of the system is ARC/INFO, an existing geographic information system that is used for storing spatial data, and ArcView was selected for displaying spatial data.

Attribute data, such as sample information, analysis results and geophysical properties, are stored in Ingres, whereas spatial information, such as the location of samples and geological features, are stored in ARC/INFO. In addition to the MDA project results, the system also stores information gathered through other Alberta Geological Survey projects. They include a digital geology map of Alberta, data from the Alberta Mineral Deposits and Occurrences file, and data from the Metallogenic project.

Data that can be retrieved include the MDA project number, name and description, the project leader, when the project began and ended, and the availability of data from the project. ARC/INFO is used to perform spatial searches based on a stored digitized outline of the study area for each MDA project. The geoscience data include tabular information, such as the location of samples and mineral occurrences, the results of geochemical and geophysical analysis, and spatial information in the form of maps.

Data can be printed or copied to disk, and maps based on any set of data can be generated. They show any combination of point data (location of commodities, mineral occurrences and samples), lines (faults, geologic contacts), or polygons (geological units.) Other features can be displayed, and any map that can be displayed can be printed.

Publications/Presentations

Chao, D.K., D.A. Wynne, L.P. Yuan and M. Price. 1995. Mineral Information System. Preliminary system. Poster Presentation and Demonstration. Fourth Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. April 6–7, 1995. Calgary, Alberta.

Rottenfusser, B., D.K. Chao, D.A. Wynne, L.P. Yuan and M. Price. 1994. Mineral Information System. Preliminary system. Poster Presentation and Demonstration. Third Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. February 10–11, 1994. Calgary, Alberta.

Wynne, D.A., L.P. Yuan, D.K. Chao and M. Price. 1996. Mineral Information System — Documentation and User Guide. Alberta Geological Survey. Open File Report 1995-10. In press.

Coordination of Geoscience Program

Geological Survey of Canada, Calgary

Project C1.61

The Canada and Alberta geoscience components of the Canada-Alberta Partnership Agreement on Mineral Development (MDA) were separately coordinated by the Alberta Geological Survey (AGS) and the Geological Survey of Canada (GSC).

These coordination tasks not only involved managing budgets and overseeing projects, but also required that the work of the Alberta and Canada researchers meshed together. Equally important, all investigations undertaken by both groups had to be discussed with, and approved by, representatives of the mineral industry.

Specifically, the GSC coordination tasks included the following:

- coordinating project planning, implementation and budgets;
- assembling GSC annual work plans and budgets from project leaders;
- ensuring that the mineral industry and the AGS concurred with GSC work plans;
- working with the Geoscience Technical Committee to ensure approval of annual GSC work plans;
- periodically assembling scientific progress reports and submitting them to provincial officials and management committees;
- ensuring effective liaison among GSC divisions;
- ensuring effective liaison with other sectors of Natural Resources Canada, other federal government departments, and Alberta and industry representatives;
- monitoring project expenditures and solving funding problems;
- preparing poster and oral presentations that summarized the progress of projects; and
- monitoring manuscripts to ensure timely release of information about project findings.

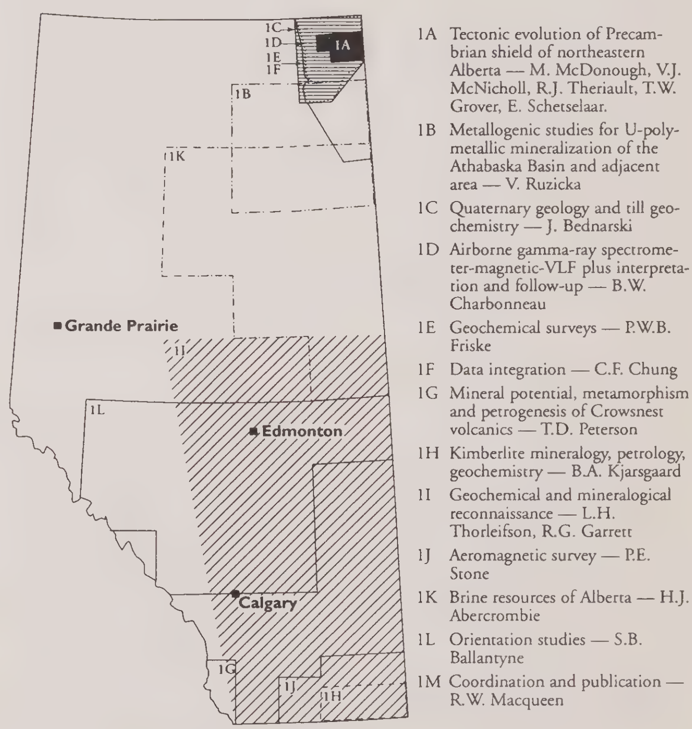
Results

When the Canada portion of the MDA program was originally approved in 1992, it comprised 12 geoscience projects and one coordination project in six sub-programs. Those sub-programs were:

- Northeastern Minerals (six projects);
- Southwestern Minerals (one project);
- Diamonds (three projects);
- Industrial Minerals (one project);
- General Sub-program (one project); and
- Coordination (one project).

Based on the success of these studies and the availability of additional funds for 1995/96, three new projects were added; two in Diamonds, and one in a new sub-program called Enhanced Geoscience Initiatives. Also, the focus of the single project in the Industrial Minerals sub-program (Brine Resources of Alberta) was changed to accommodate a surprising discovery of precious-metal mineralization near Fort MacKay.

By mid-1995/96, the 15 projects coordinated by the GSC had generated 19 published papers, 11 open file reports containing geological or geophysical maps, 9 open files of data and interpretations other than maps, and more than 30 poster presentations and 20 verbal presentations at scientific and technical meetings.



Map showing the locations of the original 12 GSC Alberta MDA projects. Not shown are the three new projects for 1995–96, the wrap-up year of the Alberta MDA. These are a study of the Cretaceous-aged Shaftesbury Formation of north central Alberta; sampling of kimberlite bodies in the Grande Prairie area; and an Enhanced Geoscience initiatives project that provided funds to several existing projects including Brine Resources and the Shaftesbury study.

Sub-program Accomplishments

Northeastern Minerals

The six projects in the Northeastern Minerals sub-program collectively accounted for approximately 58 per cent of Canada's geoscience contribution to the MDA program.

Eight new 1:50 000 scale digitally based geological maps were produced (four more to come later), which portray geological rock bodies, mineralization and relationships in a modern context. This information has extended concepts and interpretations of Precambrian Canadian Shield geology derived from the adjacent outcrop areas to the north in Northwest Territories and to the east in Saskatchewan.

Projects also documented the nature, distribution and origin of surficial materials found in northeastern Alberta, and provided more information about the geochemical composition of lake sediments and waters in the area.

Descriptions were provided of the geology and known uranium-polymetallic mineralization in the Alberta portion of the Proterozoic Athabasca Basin. They included comparisons with the commercially viable deposits of these minerals (especially uranium) that are being mined in the Saskatchewan portion of the Basin.

Digital data acquired by satellite, along with geological and geophysical data from the Alberta geoscience program, are being used to predict the statistical likelihood of discovering new metallic mineral deposits in this area.

Southwestern Minerals

The single project in this sub-program used approximately three per cent of Canada's geoscience contribution to the MDA program. GSC researchers and counterparts at The University of Calgary studied the Cretaceous-age Crowsnest Volcanics in southwest Alberta, long thought to be a possible source of gold. It was found that prospects for economic deposits are quite limited.

Diamonds

The Diamond sub-program accounted for approximately 30 per cent of GSC-managed geoscience expenditures. The initial three projects focused on diamond potential in southern Alberta. Specifically, one project generated information about the nature and origin of known minette bodies in the Sweetgrass Hills, while another involved a detailed aeromagnetic survey of the Cypress Hills. The third project, part of a larger study that included Saskatchewan and Manitoba, produced geochemical and mineralogical reconnaissance data on the soils and tills in the southern half of Alberta.

For 1995/96, two new projects were added and they focused on central and northern Alberta. One of these new investigations concerned known kimberlite bodies near Grande Prairie, while the other pursued anomalous occurrences of sulphides in the Shaftesbury Formation. These occurrences could indicate intrusive or extrusive volcanic rocks capable of hosting diamonds.

Industrial Minerals

Expenditures in the Industrial Minerals sub-program amounted to approximately three per cent of Canada's geoscience contributions. Initially, this project was concerned with the origin of subsurface evaporitic brines in Devonian strata underlying west-central Alberta. The focus shifted, however, when a new type of precious metal occurrence (called Prairie-type mineralization) was discovered near Fort MacKay. At the close of the MDA program, efforts were under way to gain a better understanding of this occurrence, especially since it was found in an environment that was previously believed to be unpromising.

General

The remaining geoscience project administered by the GSC used approximately two per cent of Canada's geoscience expenditures. It focused on the composition and distribution of gold and platinum group elements (PGE) in gravels of Tertiary and Recent age in central Alberta. The project also gathered information about the ability of ground-penetrating radar to detect the stratigraphic levels where gold and PGEs can occur.

Publications/Presentations

Boon, J. and R.W. Macqueen. 1993. The Canada-Alberta Mineral Development Agreement 1992–95: overview. Canadian Institute of Mining Bulletin. 86:968. p. 57.

Macqueen, R.W. 1996a. Exploring for minerals in Alberta: Geological Survey of Canada geoscience contributions, Canada-Alberta Partnership on Minerals (1992–1995). Geological Survey of Canada Bulletin (R.W. Macqueen, editor). In press.

Macqueen, R.W. 1996b. Summary and Conclusions (Geological Survey of Canada Alberta MDA volume). Geological Survey of Canada Bulletin (R.W. Macqueen, editor). In press.

Macqueen, R. W. 1994. Canada-Alberta Partnership on Minerals (MDA): Geological Survey of Canada projects and progress. Program and Abstracts. Third Annual Calgary Mining Forum. Calgary Mineral Exploration Group Society. February 10–11, 1994. Calgary, Alberta. pp. 43, 44. *Also*: Poster Presentation.

Macqueen, R.W. 1993. Overview: Geological Survey of Canada regional studies and the Alberta Mineral Development Agreement, 1992–1995. Program and Abstracts. The Calgary Mining Forum. Calgary Mineral Exploration Group Society. March 3–4, 1993. Calgary, Alberta. p. 4

Geoscience Coordination, Public Open Houses and Final Publication of Provincially Funded Projects

Alberta Geological Survey (Edmonton) and APEX Geoscience Ltd. (Edmonton)

Project M92-04-012

Coordination of the Alberta-funded geoscience projects within the MDA program, and promotion of the project results were provided in a separate project.

The objectives of this project were:

- to provide technical and scientific coordination of provincially funded geoscience projects;
- to maintain consistency and high standards;
- to act as a resource to the Geoscience Technical Committee;
- to attend selected conferences to promote the Alberta geoscience work; and
- to produce final publication-quality maps and reports for the Alberta geoscience projects.

Methodology

The objectives of the project were carried out by various activities. They included: conferring with project leaders before data collection began; making field visits to selected mapping projects to provide advice about field techniques and methodologies; taking an active role in the editing of draft reports and maps; advising the Geoscience Technical Committee about submitted project proposals; reviewing public information documents; coordinating geoscience presentations at various public venues; and being actively involved in the production of final project reports.

Results

Alberta supported 21 geoscience projects; 10 involved field mapping, another 10 were based on existing data sources, and the remaining project was concerned with administration.

Large geoscience projects were designed as cooperative ventures between AGS and representatives from the exploration industry or universities. Ten projects were delivered solely by the AGS, while six others were carried out solely by private industry. The others involved various partners.

There has been considerable interest on the part of industry in the Alberta projects, as evidenced by sales of project final reports and maps. Also, poster sessions and other presentations have been well attended.

Publication

Boon, J. and R.W. Macqueen. 1993. The Canada-Alberta Mineral Development Agreement 1992–1995: overview. Canadian Institute of Mining Bulletin. 86:968. p. 57.

TECHNOLOGY DEVELOPMENT

The objective of the technology development component was to enhance the competitive position of Alberta's minerals industry. This would be accomplished through the development of innovative technologies that can improve the viability of existing operations and encourage new and diversified mineral-based enterprises.

To maximize leverage of federal and Alberta government funding for technology development projects, 50 per cent industry support was strongly encouraged.

This activity supported research and development that could improve mineral and metal recoveries, while emphasizing environmental responsibility. Financial participation of the private sector was an important aspect of many projects that were selected from the following areas:

- metallic minerals;
- industrial minerals; and
- mineral processing and environment.

Metallic Minerals

Although much of the technology for metallic mineral extraction and exploration is readily available, selected technical investigations are warranted to improve the efficiency of current extraction operations and develop technologies for specific situations, in particular from Alberta's oil sands.

Excellent potential exists for the recovery of valuable metal/mineral values from oil sands tailings. This could enhance the viability of current oil sands operations and provide added incentive for new developments.

Industrial Minerals

High-bulk, low-value industrial minerals must undergo processing and modification to convert them from their raw state into economically valuable products. The technologies employed in these conversion processes differ from one mineral to another to accommodate the differing specifications that apply to each.

Furthermore, many of Alberta's industrial minerals have been categorized as marginal or sub-marginal in terms of grade for existing industrial applications. Consequently, the province's needs for high-grade minerals in several industries are met by importation. Research in processing technology could lead to new and better ways for upgrading indigenous resources, enabling them to replace costly imported raw materials and attract new industries. Phosphate and glass-grade silica are examples of minerals that are imported now because local supplies either require upgrading or more efficient extraction.

Mineral Processing/Environment

Projects were directed towards the development of environmentally and economically sound technologies to assist present and proposed mineral industry initiatives.

The Technology Development component supported specific technologies being applied to specific formations at specific sites. Some of this information is confidential for a limited time to individual developers, unless they decide to release it publicly.

Novel Technology for Gold Recovery from Alberta Placer Deposits

Envi-Tech Inc., Edmonton

Projects C2.3.1, C2.3.3 and M94-06-014

Most of Alberta's known gold is found in the sediments of major rivers or gravel that was deposited by ancient rivers. The gold in these placer deposits usually exists in small flakes called "flour," although some nuggets have been found. It is commonly extracted by simple panning or sluicing techniques, depending on whether the extraction is done by hobbyists or commercial operators. Since flour gold dominates, much of it is so fine it passes uncollected through sluice boxes, and is lost.

Envi-Tech Inc. (ET) has developed a process for the recovery of gold using a selective adsorbtion process. Since it is believed this technique can be used to recover gold from placer deposits, and do so more efficiently than by conventional methods, the objective of this study was to obtain experimental data to support or refute this contention.

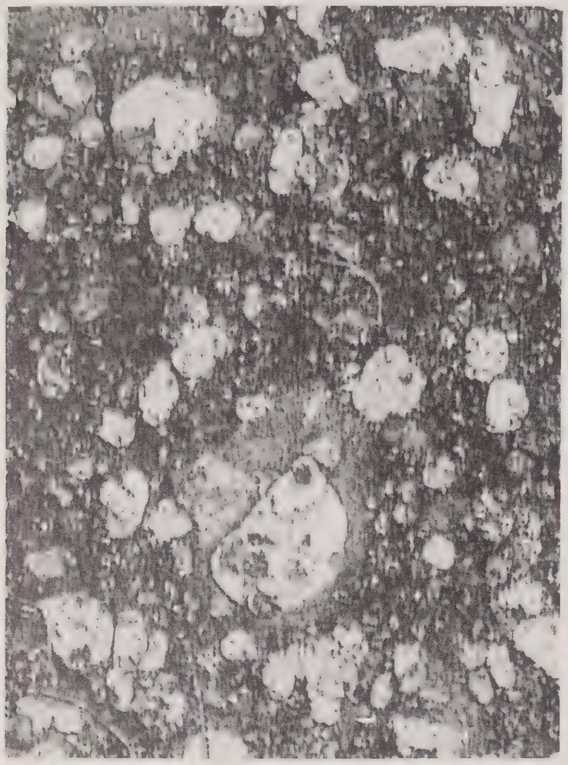
Phase I Objectives

The proposed study was divided into two phases. The objectives of Phase I were:

- collect samples of placer gold from Alberta deposits and determine their physical and chemical properties;
- prove the concept of using the ET selective adsorption method for recovering gold from these placer deposits;
- make changes to process variables, determine the results and optimize the process conditions; and
- conduct large-scale adsorption tests and compare the results with conventional gold-recovery methods.

Background

Although the exact source of the gold found in Alberta remains unknown, sufficient quantities have been discovered in the sediments of major Alberta rivers to justify recovery for the past 100 years. This is especially true for the North Saskatchewan River, where the highest concentration of placer gold has been found.



Gold particles on ET adsorbent surface. Maximum size of gold flakes is 0.6 mm.

An important characteristic of this gold is its purity; usually above 92 per cent. This is much higher than in gold nuggets, which are 60 to 80 per cent pure gold. It is believed that as Alberta gold was transported by river water to present-day locations, the usual impurities, such as silver, copper, iron and other minerals, were leached out. Therefore, the high purity of Alberta gold makes recovery economically viable, and it can be used directly without refining in jewellery and industrial applications.

Gravel deposited by ancient rivers is an especially important target for investigation because most of the gold that is present will likely be found in the fine sand that gravel-pit operators reject. Even though the gold concentration in this sand is low (0.002 to 550 parts per billion, ppb), when one considers that 45 million tonnes of gravel are processed each year, it can be estimated that the remaining volumes of reject sand may contain up to 25 000 kg of gold.

Gold Samples and Analysis

Approximately two tonnes of raw gold-ore samples were obtained from nine placer deposits (gravel pits and river sediments), and three samples of gold, recovered from ore by sluicing methods, were purchased from prospectors. In addition, the black sand concentrates resulting from traditional sluice-box treatment were obtained for two of the river-sediment samples. This allows the recovery efficiencies of gravity separation by sluicebox to be compared with ET's selective adsorption process.

It was found that rocks and pebbles larger than 12.7 mm (0.5 inch) contained no gold and could be screened out of all samples. By contrast, the rejects from sluicing contained gold particles that ranged in size from 5 microns to 120 microns.

Microscopic examination of gold flakes showed they varied in size from 0.05 mm to 0.6 mm, and they had an average thickness of 0.02 mm. These characteristics were regarded as favourable for the adsorption process since the large surface area of the gold flakes would encourage capture on the surface of the adsorbent.

Also, it was found that the particle size distribution was essentially the same in the three Alberta ore samples. This is interesting since all three came from widely separated locations.

Chemical analysis of the river-sediment and gravel-pit samples showed that some gold (1.5 parts per million, ppm) was present in the sample fraction that was smaller than 1.7 mm, but there was very little gold (less than 0.03 ppm) in the fraction that was larger then 1.7 mm and smaller than 12.7 mm. Silver and platinum concentrations were negligible. These analyses showed that 95 per cent of the gold is found in fine sand having a grain size smaller than 0.6 mm. The other five per cent is found in sand having a grain size between 0.6 mm and 1.7 mm. This means that approximately 65 per cent of the typical raw sample of gold ore can be discarded.

Initial Adsorption Experiments

A suspension of water and adsorbent is added to the sample ore, and the slurry is subjected to turbulent mixing to promote contact between the gold particles and the adsorbent. When in contact, the gold flakes adhere to the adsorbent surface and are concentrated. The adsorption process takes a few minutes, after which the adsorbent, loaded with gold particles, is separated from the slurry. This adsorbent is recycled through the process, further concentrating the gold particles. The process can be carried out in batch or continuous mode.

The ET adsorbent is a mixture of several components. By changing the components themselves, or by varying the ratio of components in the adsorbent, the adsorbing properties can be

adjusted. This provides an opportunity for the process to be modified to meet the specific needs of individual ores.

The process parameters of the selective adsorbent process have been modified to recover as much as 99% of the free particles of gold smaller than 300 µm.

A small glass, laboratory reactor was used for the initial gold adsorption studies. It simulated a stirred tank reactor, was equipped with four stainless steel impellers, and the agitation speed could be varied from 700 RPM to 3 000 RPM.

Gold adsorption studies were carried out using various gold samples and a wide range of combinations of the adsorbent components. The process also recovers any silver or platinum that may be present.

Operating conditions were varied to determine the optimum conditions for the process when carried out in the small reactor. These optimal conditions included a river-sediment gold ore, specific adsorbent components, solids concentration, and process time and temperature.

Further refinement of the operating conditions was undertaken in both the small reactor and one that was somewhat larger. This work produced reaction conditions that would be tried in scaled-up experiments.

One interesting observation came from this aspect of the work. It was noted that the ET adsorbent could be brought into contact with fresh slurries of more gold ore, and the fresh gold would be adsorbed on the surface. This recycling caused more gold to be adsorbed on each pass, typically concentrating the gold by a factor of 3.5 compared to its concentration in the raw ore. After the gold-laden adsorbent was thermally decomposed to recover solid gold, the concentration factor increased to 50:1. This means 50 kg of gold are adsorbed for every tonne of adsorbent.

The final experiments conducted in Phase I concerned comparisons among conventional gold-recovery processes and the adsorption technique. Sluice boxes that are widely used in Alberta recovered only 27 per cent of the gold in ore samples. Most of the unrecovered gold was smaller than 150 microns.

A vibration table, which is commonly used for hard-rock ores, but not for placer metals, was also tried. It was able to recover 46 per cent of the gold. The gold adsorption process, however, recovered 99 per cent of the available gold. This means the process is capable of gold-recovery rates that are similar to those using cyanide and mercury extraction, with none of the toxic, environmental by-products of these two traditional methods.

At the end of Phase I, the following general observations were made about the Envi-Tech Adsorption Process:

- the process takes no longer than 10 minutes to complete;
- the adsorbent efficiently recovers gold flour, especially smaller than 300 microns;
- the adsorbent has a high load capacity, approximately 50 kg/t;
- the adsorbent can also recover silver and platinum;
- the process is efficient, regardless of the gold concentration in its host ore, and can work on tailings, reject heaps, concentrates and hard rock deposits;
- the process is environmentally suitable; and
- scaling up did not affect the process efficiency.

Phase II Work

Phase II experiments were carried out in 1994/95. The objectives of this work were:

- construct a large-scale laboratory unit for batch processing;
- design and construct an apparatus for separating the gold-laden adsorbent from the process slurry; and
- begin using a small-scale semi-continuous processor.

  Four types of ores were used. They were:
  - placer gold ore from central Alberta;
- hard-rock gold ore from northern Ontario;
- lamproite ore from southern Alberta; and
- gold-containing limestone from northern Alberta.

The Alberta placer gold samples were similar to those used in Phase I from river sediments and gravel deposits. The hard-rock gold ore samples from northern Ontario were ground to a grain size suitable for cyanide extraction. This size is suitable for the adsorption process. The limestone ore was ground so that 55 per cent of the grains were less than 0.075 mm in size. Similarly, the lamproite was ground to a suitable size. Particle-size distributions of each gold sample were measured.

Two types of reactors were used as scaled-up batch mixers: a Denver mixing machine and a laboratory-scale tumbler processor which rotated around a horizontal axis.

It was decided that flotation would be used to separate the gold-laden adsorbent from the slurry. To accomplish this, the shaft of the Denver mixer was modified to allow air to come into contact with the slurry mixture at the appropriate stage in the process.

When the tumbler was used, the adsorbent was separated from the slurry by screening or by flotation in either the Denver mixer or a flotation column designed and constructed for this purpose.

After the operating conditions had been established using the Alberta placer gold samples, experimental work was concentrated on the other three types of gold ores.

Denver Mixer Experiments

The raw samples of hard-rock ore contained relatively high amounts of gold, from 1.3 ppm to 134 ppm, and the average percentage of the gold recovered by the Envi-Tech Adsorption Process was 92.7 per cent.

The initial experiments involving gold-bearing limestone and the original laboratory reactor resulted in recovery rates below 90 per cent. However, when tests were carried out in the Denver mixer, optimal conditions were readily established to achieve gold-recovery rates well above 90 per cent.

The gold concentration in lamproite samples was high (200–600 ppb) compared with placer samples. Subsequent recovery rates were approximately 90 per cent, with somewhat lower rates for smaller particle sizes.

Adsorbent Recycling

Using the Denver mixer and both placer and gold-bearing limestone samples, several experiments were carried out to ascertain gold-recovery rates when the adsorbent was recycled. It was found that gold recovery remained high even after seven passes, but gold recovery began to decrease after four passes. This indicated that the recycled adsorbent needed to be reconditioned. Nonetheless, after four passes, recovery rates exceeded 97 per cent and the gold loading reached 3.6 kg/t.

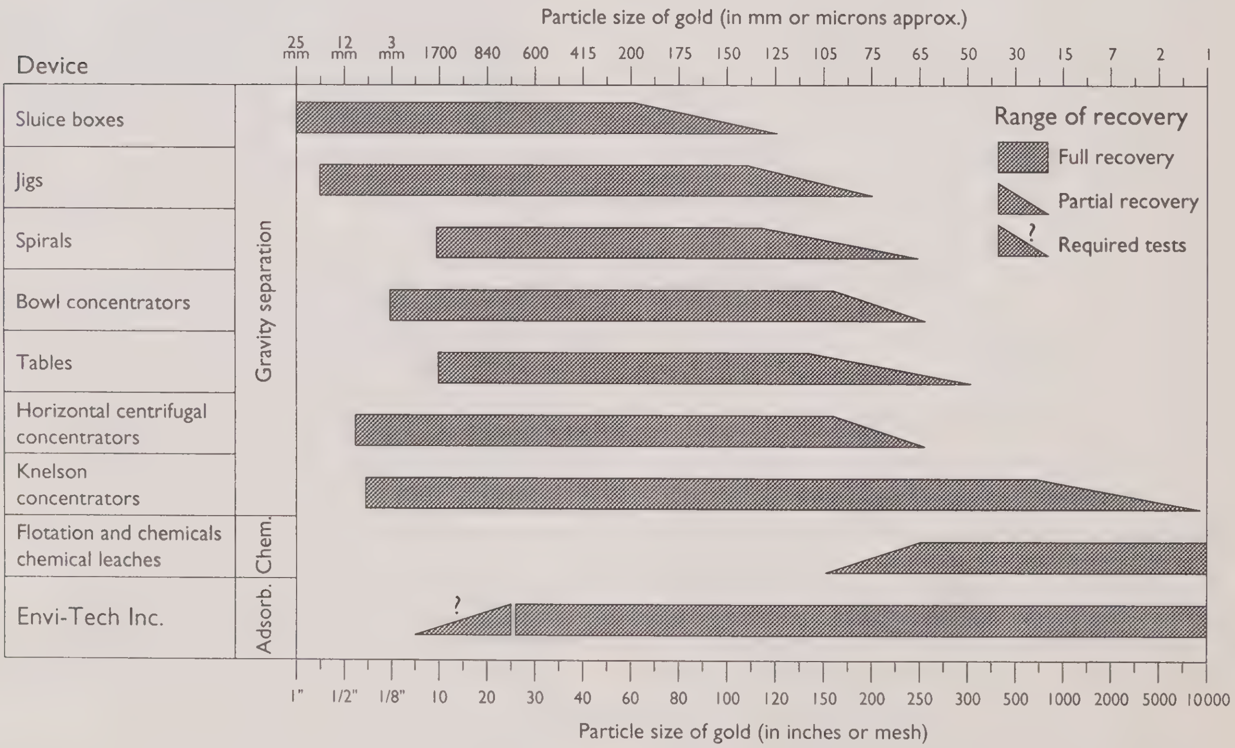
Tumbler Experiments

Using placer and limestone samples, some experiments were conducted in the tumbler processor. They showed that acceptable results could be obtained in a device that is simple, transportable and available in many sizes, and is best represented on a commercial scale by concrete mixers mounted on trucks.

Process Highlights

The ET selective adsorption process for the recovery of gold and precious metals has the following characteristics:

- operates with a recovery efficiency of 97–99% for micro diamond particles smaller than 250 μm;
- operates in a stable temperature range of 5° C to 42° C;
- operates with adsorbent and water recycling;
- allows gold load in the adsorbent up to 50 kg per tonne of adsorbent;



Comparative methods for gold recovery.

- recovers gold from alluvial deposits, hard rock ores, concentrated ores and tailings;
- provides an environmentally friendly alternative to the cyanide leaching and mercury gold recovery technologies, with a low integrating cost to existing commercial processes;
- recovers gold and precious metals in a one-step process, which simplifies the process flowsheet and reduces capital investment and operating costs;
- offers a method for testing potential precious metals deposits on site;
- provides the opportunity to recover any precious metals from deposits currently being mined for zinc, copper, nickel, etc.;
- reduces recovery time to under 10 minutes; and
- recovers gold interlocked within pyrite or arsenopyrite.

Conclusions

Overall, the Phase I and II experiments proved that the ET selective adsorption process can recover virtually all the gold present in placer deposits, hard-rock deposits, limestone and lamproite. The recovery efficiency using placer deposits was approximately three times that of sluicing methods now used. Operating conditions were established in small and larger-scale laboratory mixers, and sufficient knowledge was gained to design pilot-scale processors.

Publications

Janiak, J. and E. Miles-Dixon. 1995. Novel Technology of Gold Recovery from Alberta Placer Deposits. Phase II Final Report. Envi-Tech Inc. 92 pp.

Janiak, J. and E. Miles-Dixon. 1994. Novel Technology of Gold Recovery from Alberta Placer Deposits. Phase I Final Report. Envi-Tech Inc. 149 pp.

Engineering Design and Preliminary Feasibility of Envi-Tech Adsorption Technology for Fine Gold Recovery

TMCL Engineering, Ottawa

Project C2.3.2

Laboratory results indicate that the Envi-Tech process for fine gold recovery should be particularly successful on a commercial scale if used in the following situations:

- when an existing sand and gravel plant is to be expanded;
- a new plant is built to process an alluvial gold deposit; and
- an existing cyanide-based, gold-recovery plant is to be refurbished.

Given the commercial potential of the process, this project was undertaken to generate some preliminary engineering design and cost data for a commercial-scale operation.

Results

While the project will not be completed until later in 1996, the data for expanding an existing sand and gravel operation have been evaluated. The results indicate it would cost $2.5 million to expand a typical Alberta sand and gravel plant. When using the Envi-Tech process, this plant could produce approximately 11 500 ounces of gold per year and generate a 140 per cent return on investment before taxes.

Publication

Turak, A.A. 1996. Engineering Design and Preliminary Feasibility of Envi-Tech Adsorbent for Recovery of Gold Fines. Final Report. TMCL Engineering, Ottawa. In press.

Preliminary Study of the Environmental Impact of Envi-Tech Fine Gold Recovery Process

TMCL Engineering, Ottawa

Project M95-06-016

Among the several potential advantages of the Envi-Tech process for recovering fine gold is its ability to be less harmful to the environment than conventional processes that use cyanide extraction. Determining the extent of this environmental benefit was the purpose of this project.

Specifically, the task was to:

- do a preliminary assessment with respect to potential environmental benefits;
- evaluate the potential savings of waste treatment and disposal; and
- compare these results with conventional gold-extraction processes.

Methodology

In cooperation with the Institute of Environmental Research and Technology of the National Research Council, TMCL assessed wastewater and solid residues and compared them with allowable limits expressed in guidelines and regulations that exist in several Canadian jurisdictions. In addition, preliminary estimates were made of the cost to treat residues.

Results

Solid residues and wastewater samples were generated on a laboratory scale. Then, samples were analyzed for the presence and amounts of hazardous organic and inorganic compounds. The analysis results were compared with limits allowed in Ontario, Alberta and by the federal government. It was found that levels of organic substances in the wastewater samples from the Envi-Tech process were below the requirements of all guidelines. For example, the total organic content was below 20 ppm for samples from single-pass experiments, and it was below 5 ppm in samples of recycled wastewater. Furthermore, all samples were found to be non-toxic.

Also, the levels of all inorganic substances were below the limits of Canada's most stringent regulations.

While the final results on the economics of treating residues from the Envi-Tech process will not be completed until later in 1996, preliminary results indicate that significant savings are possible.

Publication

Turak, A.A. 1996. Preliminary Study of the Environmental Impact of Envi-Tech Process for Recovery of Gold Fines. Final Report. TMCL Engineering, Ottawa.

The Development of Enhanced Methodology for the Analysis of Indicator Minerals in Potential Diamond-Bearing Ores in Alberta

Loring Laboratories Ltd., Calgary

Project M93-06-004

When certain minerals occur in significant amounts in rock and sediment samples, they have been found to be reliable indicators that diamonds are present. The most common method for extracting and quantifying these minerals — called heavy-media concentration — is expensive and uses hazardous chemicals. Since diamond exploration in Alberta has recently become more active than at any other time, there is a growing requirement for a reliable and inexpensive method for extracting and measuring these indicator minerals.

Therefore, a project was undertaken by Loring Laboratories of Calgary to compare the effectiveness of a device called the Wilfley Half Table with conventional heavy-media concentration.

Background

Conventional heavy-media concentration involves the use of tetrabromoethane and methylene iodide as concentrating agents, but both reagents are expensive and hazardous to people and the environment. A special breathing apparatus and proper ventilation are required, and the chemicals are difficult to remove from the concentrate and the resulting tailings.

The procedure involves two steps. First, screened material is placed in tetrabromoethane. Whatever floats is removed, dried and set aside, while the material that sinks is filtered and then placed in methylene iodide. The material that floats in methylene iodide is filtered, washed, dried and retained as "Middlings." Whatever sinks is filtered, washed, dried and kept as "Heavies." Both the Middlings and Heavies are magnetically separated.

The Wilfley Half Table has been used for 50 years to concentrate minerals, and its operation poses no threat to humans or the environment. As water is continuously poured over a flat shaking bed that is slightly tilted, heavier materials are concentrated at one end while lighter materials are washed away over the side. The concentrate is then dried and weighed, and the components are magnetically separated and counted.

Methodology

Between June and September 1993, 17 duplicate samples of till were collected from various locations in Alberta. They were divided into two sets, and each set was subjected to the two media-concentration methods. The four indicator minerals of interest were garnet, pyroxene, ilmenite and gahnite.

The concentrated samples were separated into magnetic and non-magnetic fractions. The magnetic fractions were set aside and the remaining fractions were further separated into non-magnetic, paramagnetic and weakly paramagnetic components. Then, a binocular microscope was used to observe the grains of indicator minerals. These grains were picked out of the samples and the quantities of each type were recorded. The

grains were mounted in epoxy plugs, polished to expose their surfaces and then they were examined by an electron microscope (Energy-Dispersive Semi-quantitative analysis, EDS) and graded by Electron Microprobe analysis.

Results

The conventional method produced 373 grains of possible indicator minerals. After EDS analysis, 126 garnets, 56 pyroxenes, six ilmenites and seven gahnites were identified for Electron Microprobe analysis. The Wilfley method produced 406 grains. Following EDS analysis, 118 garnets, 73 pyroxenes, 10 ilmenites and 11 gahnites were identified.

Conclusions

It was concluded that both media-concentration methods produced similar quantities and qualities of indicator minerals, thus demonstrating that the Wilfley Half Table was suitable for the task. It was also noted that a new device called the KMS Water Column System should be tested in conjunction with the Wilfley method since it is capable of removing all the silica and quartz from non-magnetic fractions.

Publication

Loring Laboratories Ltd. 1994. The Development of Enhanced Methodology for the Analysis of Indicator Minerals in Potential Diamond Bearing Ores in Alberta. 17 pp., appendices.

Establishing Diamond Exploration Sample Processing Methodology and Facilities for Alberta

TerraMin Research Labs Ltd., Calgary

Project M93-06-003

When the MDA program began, diamond exploration was a relatively new phenomenon in Alberta, and no laboratory existed for the purpose of processing samples thought to be diamond bearing.

Therefore, the objective of this project was to establish the required processing and analytical facility. This meant determining the characteristics of field samples, ascertaining the requirements for sample preparation, evaluating processing equipment and mineral-isolation equipment, designing and installing a processing system and a mineral-picking system, and developing a process for analyzing mineral grains.

Field Samples

In determining the size of field samples, a compromise must be chosen between what is logistically feasible and what is statistically desirable. Based on experience elsewhere, the following sample sizes were recommended:

- till — 10–35 kg;
- sediment — 5–20 kg; and
- rock and drill core — 20–50 kg.

Bulk Sample Preparation

Bulk till or sediment samples must be processed in such a manner that grains of a certain size can be isolated. The desirable size ranges were determined to be 2 500–500 microns and 500–200 microns. Also, it must be possible to examine grains smaller than 200 microns for the presence of microdiamonds. Following a period of testing, specific pieces of equipment were found capable of disaggregating, dispersing, wet screening and milling bulk samples to obtain the desired grain sizes.

Mineral Separation

While gravity separation can be used to isolate diamond-indicator mineral grains, the equipment available to achieve this separation was found to be unsatisfactory. Either the mineral recovery rates were less than 90 per cent of the heavy minerals, or the concentrates contained unacceptably high amounts of light minerals.

Consequently, a novel separator was designed and built. It produced the desired separation with a 98 per cent recovery rate for heavy minerals. The process is capable of separating 3 000–4 000 grams of sample an hour. In addition, the heavy mineral fraction can be further separated according to magnetic properties.

Hand Picking of Minerals

Mineral grains that might contain diamonds are usually hand picked from prepared samples and then examined under a microscope. A special glass-topped turntable was designed and built to facilitate this manual operation.

Elemental Analysis

Confirmation of indicator minerals is achieved by elemental analysis of grains using a Scanning Electron Microscope and an Energy-Dispersive X-ray Analyzer or an Electron Microprobe. It was decided that this specialized service was best provided by lab-

oratories capable of providing a high level of precision, but none exist in Alberta. Consequently, the services of one such lab in Ontario were tested and found to be satisfactory.

Conclusions

As a result of these developments, TerraMin Research Labs Ltd. is now able to provide all the necessary analytical services that are required by Alberta diamond explorationists.

Publication

Report on Establishing Diamond Exploration Sample Processing Methodology and Facilities for Alberta, TerraMin Research Labs Ltd. 9 pp. In press.

Diamond Recovery by Selective Adsorption

Envi-Tech Inc., Edmonton

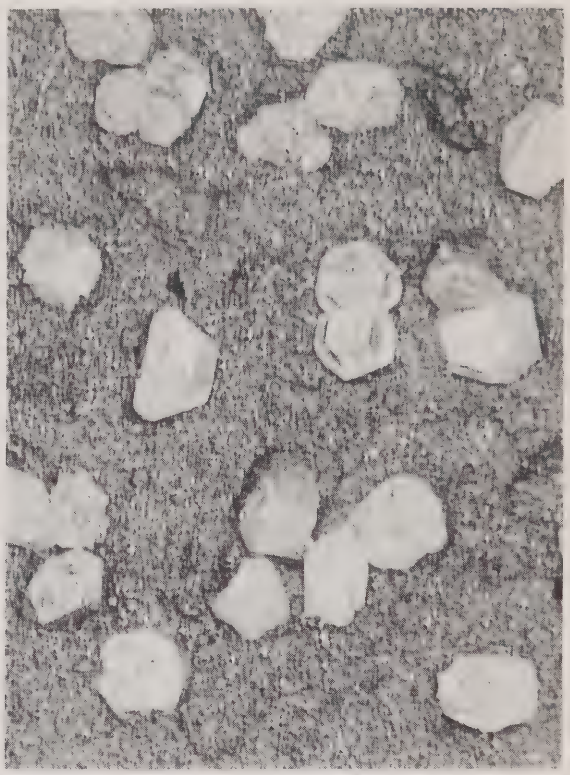
Projects M94-06-011 and C2.3.4

The Envi-Tech Adsorption Process has been used successfully to recover gold from placer gold deposits, and the recovery rates have been well over 90 per cent. The process is especially effective at recovering gold particles smaller than 300 microns, which cannot be captured by conventional gravity separation processes. Given the attributes of the process, it was applied in this project to the recovery of diamonds from various diamond-bearing ores. In particular, it was believed that the process would recover microdiamonds smaller than 500 microns. Diamonds this small are not recovered by conventional technologies, but could be used in industrial applications, and as a tool for the evaluation and development of diamond deposits.

Methodology and Results

Nine samples of diamond-bearing ores were obtained for initial testing. They included five lamproites from southern Alberta, two kimberlite ores from Ontario and British Columbia, and two river sediment samples from central Alberta. The general process conditions were established using a large sample of one of the lamproite ores from southern Alberta. This ore was crushed and the size distribution of the particles was measured.

The adsorber used in this process was similar to those used in the gold-recovery project (See *Novel Technology of Gold Recovery from Alberta Placer Deposits*). It comprises solid and liquid components. This allows the ratio of each component to be adjusted to accommodate differing characteristics of each ore and achieve better adsorption.



Diamond particle (maximum size ≃ 0.5 mm) on ET adsorbent surface.

The ET process, which occurs in a suspension in water, requires good contact between the diamond particles and the adsorbent. A laboratory mixer was used to establish the general process conditions. Synthetic and natural diamonds, ranging in size from 125 microns to 841 microns, were used to simulate the diamonds that could be present in the various ores. These diamonds (initially limited to the size range 125–180 microns) were mixed homogeneously with ore samples to allow any ore effects to be experienced. Then, slurry mixtures having 20 per cent solids were prepared and the adsorbent was added. After diamond particles were captured on the adsorbent surface, they were separated from the slurry by wet screening or flotation. Finally, the diamonds were recovered by thermal decomposition of the adsorbent.

Among the general process conditions that were established using the southern Alberta lamproite ore was the temperature that could be safely used to heat the adsorbent-diamond mass after adsorption. This temperature must be capable of decomposing the adsorbent without causing any significant weight loss

Several process variables were changed to determine whether the diamond-recovery efficiency would be affected. For example, the diamond concentration and the slurry concentration were altered, but neither had any noticeable effect on the results within the range of concentrations tested. In every case using the southern Alberta lamproite/diamond mixture, the diamond-recovery rate was 99 per cent.

Some variation in the diamond-recovery rate was noticed when the characteristics of the adsorbent were changed, but this was expected and confirmed the belief that optimal conditions must be established for each ore sample.

Processing time was also varied. It was found that a one-minute processing period was usually sufficient time to achieve recovery rates of 98 per cent.

Perhaps the largest change was observed in tests to determine the recovery rates for various ranges of diamond particle size. Here, it was clear that the recovery rates for larger particles (greater than 297 microns) were significantly lower than for particles ranging in size from 125 microns to 297 microns, under these operating conditions.

Once the general operating conditions were established using a single lamproite sample from southern Alberta, the other ores were tested. Once again, they were mixed with diamonds ranging in size from 125 microns to 180 microns. While the diamond-recovery rates varied from ore to ore, it was believed that simple alterations to the processing conditions could be made to maintain recovery rates higher than 90 per cent.

Process Highlights

The ET selective adsorption process for the recovery of diamonds has the following characteristics:

- operates with a recovery efficiency of 97–99% for micro diamond particles smaller than 250 µm;
- operates in a stable temperature range of 3° C to 43° C;
- operates with adsorbent and water recycling;
- allows micro diamond load in the adsorbent up to 6 kg per tonne of adsorbent;
- offers a method for on site evaluation of diamond deposits based on recovered micro diamonds;
- recovers micro diamonds from ores in a one-step process, which simplifies the process flowsheet and reduces capital investment and operating costs;
- provides an environmentally friendly method for separating diamonds without using hazardous chemicals, or discharging waste streams; and
- reduces recovery time to under 10 minutes.

Conclusions

Processing conditions were established for diamond recovery from several diamond-containing ores. Since the process was found to be especially effective at recovering diamonds smaller than 300 microns, it was suggested that the process might be particularly useful for evaluating the microdiamond content of raw ores.

Publications

Janiak, J. 1995. Diamond Recovery by Selective Adsorption. Phase I Final Report. Envi-Tech Inc. 125 pp.

Janiak, J. 1996. Diamond Recovery by Selective Adsorption, Phase 2, Final Report. Envi-Tech Inc. In press.

Heavy Minerals Recovery from Syncrude and Suncor Centrifuge Plant Tailings

Alberta Chamber of Resources, Edmonton

Project C2.1.1

It has long been known that heavy minerals present in Alberta's oil sands are selectively enriched as they pass through the bitumen-recovery processes used by Suncor and Syncrude and are expelled in the tailings from the centrifuge stage. Since these minerals are valuable, it has been reasoned that their recovery could substantially improve the economics of synthetic oil production. In particular, two elements — titanium and zirconium — are present in sufficient concentrations that they could represent five per cent of the world's supply if they could be recovered from the tailings. Therefore, this project was initiated under the leadership of the Alberta Chamber of Resources, with participation by several companies and research agencies.

The two principal objectives of the project were:

- to prove the existence of heavy minerals in oil sands and estimate their concentration in centrifuge plant tailings; and
- to determine whether heavy minerals recovery from the centrifuge plant tailings is technically feasible and commercially viable.

Methodology

Gravimetric upgrading of heavy minerals is commonly used in several countries, but the results of earlier studies indicated that the complexity of the oil sands and the presence of residual

bitumen might interfere with the process. It was expected that flotation would enrich both the heavy minerals and the bitumen by a factor of two or three. In this case, the centrifuge plant tailings already contain approximately 13 per cent titania (TiO_2), three per cent zirconia (ZrO_2), and three to five per cent bitumen.

Consequently, a four-step process was proposed for separating and concentrating the heavy minerals present in the centrifuge plant tailings: (1) hydrocycloning to remove clays and some bitumen; (2) flotation to reject silica (SiO_2), followed by; (3) high-temperature combustion to remove bitumen, pyrite and other agglomerating substances; and (4) conventional mineral processing to produce individual high-grade products according to market specifications. Process development was to be accompanied by mineralogical and chemical studies aimed at understanding the composition and the characteristic properties of all the mineral components of interest.

Most of the experiments were conducted by the Canada Centre for Mineral and Energy Technology (CANMET), with assistance from Acme Laboratories, AGAT Laboratories, F.D. McCosh & Associates, Minoretek Consultants, Sherritt Inc., H.A. Simons Ltd., Suncor Inc., Syncrude Canada Ltd., TMCL Engineering and the University of Alberta.

Flotation Experiments

Initial bench-scale flotation tests were carried out by CANMET on tailings slurries from Suncor Pond No. 1. Initially, flotation procedures were developed to produce a stable froth that contained more than 80 per cent of the total bitumen and heavy minerals. After further experimentation at a pilot scale, improvements to the process yielded up to 99 per cent recovery of the titania and zirconia. The concentrations of the recovered titania and zirconia were 28.5 and 10.4 per cent, respectively.

Some adjustments to the procedures were necessary when centrifuge tailings from Syncrude were tested. Recovery rates averaging 95 per cent were achieved for both titania and zirconia, and the concentration of the two minerals was 28.7 and 7.7 per cent, respectively.

Mineralogical and X-Ray Diffraction analyses of the cleaned concentrates identified rutile ($\sim TiO_2$), leucoxene ($\sim FeTi_2O_5$), zircon ($\sim ZrSiO_4$), simple and complex iron-aluminum silicates (quartz, garnet, tourmaline, mica), siderite ($FeCO_3$), pyrite ($\sim FeS_2$), ilmenite ($\sim FeTiO_3$), monazite ($\sim CePO_4$), graphite, chromite and traces of other minerals.

Thermal Analyses

Thermogravimetric and Differential Thermal Analysis experiments were carried out on the concentrates, and Fourier Transform Infrared analysis was used to analyze the gaseous products. It was found that most of the weight loss occurred as CO_2, SO_2, H_2O and traces of CO were evolved. A weight loss of 11 per cent was attributed to the decomposition of bitumen, pyrite and siderite, and the formation of hematite (Fe_2O_3). Thermomagnetometry was also used to detect any changes in the magnetic properties of the materials being tested.

The tests indicated that oxidizing roasting in air should be the most suitable way to prepare materials for further processing. Larger scale tests in a rotary kiln provided adequately roasted samples. A fragile iron oxide coating was present on all materials, which inhibited mineral processing.

Mineral Dressing

After various separation techniques were tried, the most effective procedure involved the following steps: (1) attrition scrubbing to remove the iron oxide coating; (2) screening on a +65 mesh to remove coarse garnets and graphite; (3) treatment of the –65 mesh material using a low-intensity magnetic field to remove approximately 10 per cent of the calcine. The resulting material is a high iron-containing ilmenite (+20 per cent Fe, 50 per cent TiO_2). Use of a wet gravity table separated the remaining material into three components: (1) approximately 30 per cent light material and more than 70 per cent SiO_2 tailings; (2) approximately 15 per cent heavy material and more than 50 per cent ZrO_2 concentrate, which produces zircon (+90 per cent $ZrSiO_4$), monazite (+15 per cent Ce), and a by-product stream containing chromium and gold; and (3) approximately 55 per cent raw Ti-middlings ($\sim$50 per cent TiO_2), that is then separated by using a high-intensity magnetic field and reverse flotation into tourmaline, rutile (+90 per cent TiO_2) and leucoxene (+20 per cent Fe_2O_3, $\sim$70 per cent TiO_2).

Based on this work, it is estimated that more than 65 per cent of the desired minerals can be recovered in marketable concentrates. A full-scale plant to recover these minerals would cost approximately \$40 million to build and \$8 million a year to operate. These numbers represent production costs of approximately \$50 a tonne of TiO_2 contained in the products, which are comparable to those experienced by major producers. This indicates that positive revenues are likely.

Future

At the close of the MDA program, several initiatives were under way to gather additional information about this process and determine its commercial viability. These included marketing and upgrading tests by Sherritt Inc. and an economic prefeasibility study by H.A. Simons Ltd. Critical work in the next phase consists of a large-scale (1 000 tonne) demonstration in Alberta.

Publications

Hamer, C.A., A. Putz, S.A. Mikhail, J. Wilson, V. Razbin, S. Madrala and M. Raicevic. 1995. Heavy mineral recovery from Syncrude and Suncor centrifuge plant tailings. Progress Report No. 1. Mineral Sciences Laboratories Division Report MSL 95-047 (IR). CANMET.

Healy, R.E. 1995. Mineralogical characterization of Ti- and Zr-bearing minerals in the oil sands. Final Report. Minoretek Consultants.

McCosh, F.D. 1995. Geological studies for mineral co-product project. Progress Report and Proposal. F.D. McCosh & Associates.

Mikhail, S.A., A.M. Turcotte and C.A. Hamer. 1995. Application of thermal techniques in the recovery of heavy minerals from oil sand tailings. Minerals Sciences Laboratories Division Report MSL 95-13 (OP&J). CANMET.

Owen, M. 1995. Mineral Development Agreement co-products study. Report and Pre-Feasibility Study. H.A. Simons Ltd.

Plitt, L.R. and A.A Turak. 1995. Visman automedium cyclone testing. Preliminary studies for the development of a simplified flowsheet for recovery of titanium and zirconium minerals from oil sands extraction plant tailings. Final Report. University of Alberta and TMCL Engineering.

Tan, K.G. and M. Raicevic. 1996. Heavy mineral recovery from Syncrude and Suncor centrifuge plant tailings. Final Report. CANMET.

Turak, A.A., A. Majid and F. Toll. 1995. Recovery of titanium and zirconium minerals present in oil sands centrifuge tailings by agglomeration with coke and bitumen. Preliminary Laboratory Investigation Report. TMCL Engineering and National Research Council.

Microwave Smelting of Low-Rank Coal and Oxidic Minerals

Alberta Research Council, Edmonton

Project C2.1.2

Chemical reduction of metal oxides using carbon is the principal method for producing metals such as iron, tin and zinc. Normally, this involves two simultaneous reactions, but recent work using microwave energy and pulverized coal suggests it may be possible to perform the task in one step. Therefore, a screening study was undertaken at the Alberta Research Council to determine whether low-rank Alberta coal could be used to reduce several metal oxides in the presence of microwave energy.

Background

It is believed that conventional metal-reduction involves two reactions. In steelmaking, for example, a blast of hot air contacts a mixture of iron oxide and carbon (in the form of coke). Initially, carbon dioxide (CO_2) is formed, which is then reduced to carbon monoxide (CO) by the carbon. This is followed by reduction of the iron oxide by CO:

(1) $CO_2 + C = 2CO$

(2) $FeO + CO = Fe + CO_2$

Recent microwave experiments suggest that a pelletized mixture of coal and iron oxide might be more evenly heated when exposed to microwaves, and this could cause reduction in a single step:

(3) $FeO + C = Fe + CO$

Furthermore, this reaction might be applicable to high-value ores that are not easily refined by any of the conventional processes.

Methodology and Results

Since Alberta has abundant supplies of coal — particularly low-rank coal which is known to be highly reactive — and the oil sands contain high-value titanium and zirconium oxides, the objective of the study was to assess the potential of microwave heating for producing high-value metals or metal alloys.

Two carbon sources were chosen: sub-bituminous coal from the Highvale mine, near Edmonton, and carbon black manufactured by CANCARB Ltd. in Medicine Hat.

Ten mineral ores were studied. They were:

- molybdenum trioxide from Fraser Lake, British Columbia;
- molybdenum sulphide from the same source in British Columbia;
- molybdenum sulphide from Montana;
- nickel sulphide, a nickel-cobalt sulphide supplied by Sherritt Inc. in Fort Saskatchewan;
- lead-zinc sulphide from Trail, British Columbia;
- Baymag magnesite, a magnesium carbonate ore from Radium, British Columbia;
- Clear Hills iron from Alberta;
- Burmis magnetite, from the Pincher Creek area of Alberta;
- Dungarvan Creek magnetite from another source near Pincher Creek; and
- Suncor sand tailings, a heavy mineral concentrate, containing titanium and zirconium.

Two microwave systems were used. One, at Queen's University in Kingston, Ontario, supplied pulsed radio-frequency waves at 40 MHz, while the second, at the University of Alberta, provided a continuous source of microwave energy at 915 MHz.

Queen's University Studies

Initial experiments at Queen's University showed the sub-bituminous coal was more reactive, so it was used in all subsequent tests. Samples comprising powdered coal (150 mg) and powdered ore (500 mg) were then prepared and irradiated. The facilities at Queen's allowed collection of any gases that evolved, and they were analyzed for carbon dioxide and sulphur dioxide. Levels of both gases above those expected from coal alone would indicate that the coal and the ore were interacting, and the ore was being reduced.

The investigations at Queen's University showed that molybdenum oxide and molybdenum sulphide did not react with coal. In the absence of coal, nickel sulphide and the Suncor concentrate absorbed energy and reacted, and there was some visual evidence that some other ores reacted with coal.

University of Alberta Studies

The facilities at the University of Alberta were modified so the power absorbed by each sample and the sample temperature could be monitored. Also, it was possible to determine the heat-transfer loss from the heated zone.

Tests were performed on the following samples:

- sub-bituminous coal from the Highvale mine;
- Suncor sand tailings;
- nickel sulphide;
- molybdenum trioxide;
- a 50:50 mixture of Highvale coal and Suncor sand;
- a 50:50 mixture of Highvale coal and molybdenum trioxide; and
- a 50:50 mixture of Highvale coal and nickel sulphide.

Scanning Electron Microscopy (SEM) was used to analyze some raw and microwave-treated samples for their elements and to observe any physical changes that might have occurred. Also, selected raw ores and microwave-treated samples were examined by X-ray Diffraction for changes in crystalline structure.

The ore samples responded to microwave energy as follows:

- molybdenum trioxide was converted to molybdenum dioxide, accompanied by evolution of carbon dioxide and changes in physical and crystalline properties;
- molybdenum sulphide showed no apparent changes;
- the nickel-cobalt sulphide lost oxygen, evolved carbon dioxide and experienced some physical changes;
- the lead-zinc sulphide lost oxygen and evolved carbon dioxide, but no physical changes were noted;
- both the magnesite and magnetite ores showed no changes; and
- Suncor sand alone lost some oxygen and formed large molten particles. In the presence of coal, these particles had a distinct crystalline structure.

The estimated heat transfer losses from samples were approximately the same as the power absorbed by each sample. This did not allow any calculation of the energy costs that might be incurred. Consequently, energy comparisons with conventional smelting could not be made.

Conclusions

It was concluded that some ores do respond to microwave energy and that molybdenum trioxide, nickel sulphide and the Suncor sand should be studied further. Certain modifications to the reaction conditions should be tried.

Publication

Chambers, A.K., G. Morrison and R. Richardson. 1995. Microwave Smelting of Low-Rank Coal and Oxidic Minerals. Final Report. Alberta Research Council. 53 pp., appendices.

Clay Carbo-Chlorination Study

H.A. Simons Ltd., Calgary

Project C2.2.2

Worldwide demand for aluminum continues to grow, and the options for producing it are also expanding. The Toth Clay Carbo-Chlorination Process, developed in the U.S.A., makes high-purity aluminum chloride and other chlorides from raw materials that are found in Alberta and other parts of western Canada. These chlorides can then be further processed to recover aluminum, other metals and various commercially valuable products.

The objective of this study was to examine various potential raw materials available in Alberta for their suitability in the Toth process, and then perform cost-benefit analyses for constructing a commercial-scale facility in Alberta, including estimates of capital and operating costs and potential revenues.

Background

Most of the world's aluminum smelters use the Hall-Héroult process to make aluminum from bauxite. The largest deposits of this mineral, $Al_2O_3{\cdot}2H_2O$, are found in tropical or sub-tropical countries such as Jamaica, Australia and Brazil. Canada is one of the world's largest producers — and the world's leading exporter — of aluminum, but imports all its bauxite (and alumina, Al_2O_3) from other countries. Since aluminum is made by electrolysis, Canada is able to compete in world markets because it has relatively inexpensive hydro power.

In addition to bauxite, which contains more than 40 per cent alumina, many minerals contain aluminum, including kaolin (commonly known as china clay), alunite and anorthosite. It is also found in oil shale, oil sands and flyash resulting from coal combustion. Aluminum researchers have experimented with a number of processes to produce aluminum economically from these and other sources.

It has been estimated that more than 45 million tonnes of clays having an alumina content greater than 25 per cent exist in Canada. Saskatchewan has substantial reserves of kaolinitic clays, and Alberta has clays worth considering in coal seams near Edmonton, as well as native clays and tailings at Fort McMurray.

One method capable of using some of these alternative aluminum sources is the Toth Clay Carbo-Chlorination Process. It was developed using clays that have an alumina content of approximately 38 per cent, and can be used to recover products derived from other minerals.

Reactive clay, chlorine and a reactive source of carbon are combined to produce the following reactions involving various minerals present in the clay:

(1) $Al_2O_3 + 3Cl_2 + 3C = 2AlCl_3 + 3CO$

(2) $SiO_2 + 2Cl_2 + 2C = SiCl_4 + 2CO$

(3) $TiO_2 + 2Cl_2 + 2C = TiCl_4 + 2CO$

The four principal steps in the process are:

- calcination of clay with a sulphur catalyst;
- carbo-chlorination of the calcined clay, using a sulphur catalyst;
- separation and recovery of metal chlorides; and
- purification of the metal chlorides.

The following products could be produced from carbo-chlorination of clays:

- high-purity anhydrous aluminum chloride;
- silicon tetrachloride;
- metallic aluminum;
- basic (or poly-) aluminum chloride;
- fumed silica;
- polycrystalline metallic silicon;
- titanium tetrachloride;
- titanium dioxide;
- metallic titanium;
- high-performance specialty aluminas; and
- other metals, metal chlorides and derivatives.

The Toth Clay Carbo-Chlorination Process has been licensed to WestCAN Chemicals Inc. of Calgary.

Methodology

Three major sources of raw materials were identified in Alberta and Saskatchewan. They are:

- Fort McMurray
  - high-alumina fine tailings (21 per cent alumina)
  - upgrader coke
- Central Alberta
  - kaolinitic overburden and partings at coal mines (30 per cent alumina)
  - high-alumina flyash (20–26 per cent alumina)
  - coke from several sources

- Southern Saskatchewan/Southeastern Alberta
  - commercial-grade kaolinitic clays (up to 34 per cent alumina)
  - low-grade kaolinitic sand (22 per cent alumina)
  - lignite char

Carbo-chlorination tests were carried out on fine tailings and beach sand from the Fort McMurray area, partings from Alberta coal seams, flyash from power plants, several clays from Saskatchewan and British Columbia, and coal-preparation rejects from British Columbia. Two clays from Georgia were used as references.

Carbon sources included oil sands coke, upgrader coke, carbon black, oxidized coal, metallurgical coke, wood char and lignite char.

Each clay was analyzed for mineralogy, chemical composition and loss on ignition, while the carbon sources were subjected to standard tests for proximate analysis, ultimate analysis, calorific value and mineral ash analysis.

Initially, one-gram samples of clay and a standard char or coke were chlorinated in a Thermogravimetric Analyzer (TGA). This generated data on the overall reactivity and an initial rate of reaction.

It was found that the overall clay reactivity increased with higher alumina content.

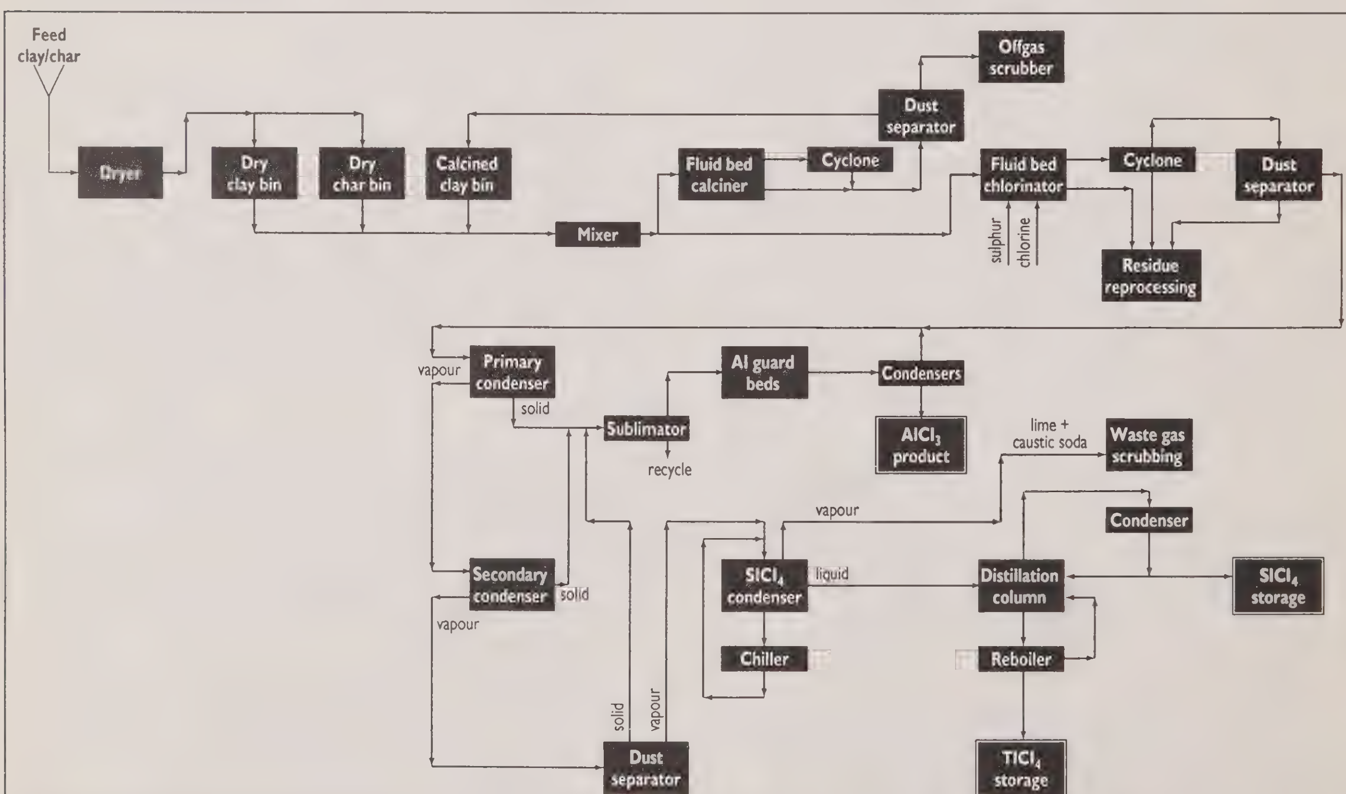
Following the TGA studies, 30-gram samples from a select group of raw materials were chlorinated in a laboratory-scale fluidized-bed reactor. Residue and gases were collected and analyzed to determine the composition and amounts of end products.

A marketing analysis was carried out to determine the current and projected values of several chemicals that could be produced by the carbo-chlorination process.

An economic analysis was performed to obtain capital costs, operating costs and revenues for commercial-scale carbo-chlorination plants in each of the three regions where raw materials are available.

Two plant sizes were considered: (1) a 50 000 t/y chloride facility, which requires 50 000 t/y of clay and 15 000 t/y of coke (or equivalent); and (2) a 350 000 t/y aluminum smelter, which requires 3 million t/y of clay and 1 million t/y of coke.

It is believed that a 50 000 t/y chloride plant could not generate sufficient revenue to justify opening a dedicated clay quarry. Thus, it is assumed that the clay will come from an existing



Toth Aluminum Corporation pilot plant simplified flowsheet.

pit and the coke will be supplied by an existing production process. These limitations do not apply to the aluminum smelter, but having to avoid a dedicated quarry and coke-production plant improves the economics. Oil sands coke, heavy oil coke and coal are currently produced in sufficient quantities for an aluminum smelter.

Results

Approximately eight million tonnes of oil sands fine tailings are produced each year in Alberta. The aluminum content of this raw material could support two 350 000 t/y aluminum smelters. The oil sands beach sands were found to be low in aluminum, but high in titanium. Therefore, this raw material could be used to produce titanium tetrachloride, a precursor of pigment-grade titanium dioxide.

Kaolinitic clays from British Columbia, southern Alberta and southern Saskatchewan were all reactive. In particular, the southern Saskatchewan clays are sufficiently abundant to support 10 aluminum smelters for 25 years.

Coal mining wastes (except for a bentonite sample) were sufficiently reactive. Some additional investigation is required to match the sources of these materials to suitably sized chloride plants, but the initial results are promising.

Four carbon sources were found to be suitable: heavy oil coke, carbon black, lignite char and charcoal. There is enough of these to support a chloride plant.

A comparison of capital and operating costs with projected revenues of a chloride plant indicates that attractive returns on investment are possible under several circumstances. The economics of an aluminum smelter are encouraging at this stage, but further investigations are necessary.

Conclusions

Since the smelter would depend on a chloride plant, and the economics of a chloride plant are promising, it was recommended that a chloride plant be built. Meanwhile, the economics of an aluminum smelter should be developed in more detail on a world scale.

Publication

H.A. Simons Ltd. 1995. Carbo-Chlorination Screening Study. Final Report. 165 pp., appendices.

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Financial support was provided by the Canada-Saskatchewan Mineral Development Agreement for testing performed on selected raw materials from Saskatchewan.

Development of an Expanded Light-Weight Plaster Structural-Type Building Product for Agricultural or Light-Weight Industrial Use

Polar Powders & Technologies Inc., Calgary

Project M93-06-002

High-strength — yet light-weight — building blocks made from a product known as aerated concrete are used in Europe in place of conventional concrete in various applications. Those with low compressive strength can be used in the external walls of agricultural or light-weight industrial buildings. Those having higher compressive strength can be used either in reinforced concrete roof and wall units or as load-bearing wall slabs. Their lower weight makes them less expensive to transport, and they are easier to handle and erect on building sites.

European aerated concrete is usually made from silica, cement, lime and water. This results in a porous structure, which gives rise to both light weight and high strength.

A naturally occurring material — zeolite — is porous in its natural state. Therefore, it was believed that incorporation of this material in an aerated-concrete formula might make a superior product. Preparing and testing this product, and determining the sources in Alberta of the necessary raw materials were the principal objectives of this study.

Raw Materials

Silica sand deposits are widespread in Alberta; lime is manufactured at Exshaw near Banff and in the Crowsnest Pass; and major producers of cement are found in Exshaw and Edmonton. There is no known supply of zeolite in Alberta, however, although it is suspected there might be deposits in southwestern Alberta. The closest sources are in British Columbia.

Test Products

Several aerated-concrete formulations, using zeolite combined with small quantities of silica, were prepared and tested at the Institute for Research in Construction (IRC), at the National Research Council in Ottawa. While the formulations and detailed laboratory results are confidential, aerated concrete products were successfully prepared and could be made over a range of desirable compressive strengths.

Product Properties

Lightweight Zeolite Concrete (LZC) can be less than 25 per cent the weight of solid concrete, and the density can be varied to meet specific engineering requirements. For example, three products having the following densities and compressive strengths, respectively, were prepared by IRC: (1) 750–1 000 kg/m^3; 7.5–10 MPa, (2) 1 000–1 250 kg/m^3; 10–20 MPa, and (3) 1 250–1 500 kg/m^3; 20–30 MPa.

LZC blocks can be produced with levels of dimensional accuracy and stability that are much better than those of conventional concrete, and they can be sawn, drilled and nailed as though they were wood. This adds considerably to their flexibility as building materials. LZC is also non-combustible and is impervious to insects, fungi and rot.

Future

Further development is underway to optimize the formulations for commercial-scale production of Lightweight Zeolite Concrete, and additional research is needed to measure the long-term durability of the product.

Publication

Hogg, L.E.W. 1994. Development of an Expanded Lightweight Plaster Structural Type Building Product for Agriculture or Lightweight Industrial Use. Polar Powders & Technologies Inc. 13 pp., appendices.

Project Management

CANMET, Ottawa

Project C2.0.1

This project was established to provide funding for a federal representative to act as Co-chairman of the Technical Committee and undertake the duties of that position.

During the lifetime of the MDA program, these duties included:

- participating in meetings and discussions with other Technical Committee members;
- participating in meetings with Alberta industries, representatives of various organizations, other CANMET staff and the staff of various government departments; and
- reviewing project proposals and making recommendations to the Management Committee for project funding.

Also, the position included supervision of one CANMET staff member in Saskatoon who assisted Alberta and other western provinces with their MDA programs.

ECONOMIC DEVELOPMENT

The aim of the Economic Development component was to develop and promote the non-petroleum mineral sector of Alberta by identifying and analyzing the market potential for metallic and industrial minerals.

Examples of activities include mineral market commodity studies and resource management studies. These activities were aimed at encouraging private sector investment in Alberta's mineral industry.

Diamond Market Study

Maple Leaf Resources, Edmonton

Project M94-08-011

The search for diamonds in Northwest Territories (NWT) has caused the greatest claim-staking activity Canada has ever experienced, and it has spread to Alberta and other nearby areas. Apparently, it is believed there is a good likelihood that economic deposits of diamonds can be found, but what effect would such a mine have on the marketplace? Would the mine be profitable? Can the marketplace absorb a new source of diamonds? To answer these and other questions, Maple Leaf Resources investigated the little-known world of diamond mining and marketing.

The Diamond Business

The first thing that must be understood about the diamond business is that much of the mining and marketing is controlled by one company: DeBeers. This company, in conjunction with its subsidiary the Central Selling Organization (CSO), owns, produces in partnership, or has under contract, 80 per cent of annual, global rough-diamond production. At the very least, this makes DeBeers and its partners a cartel, and some describe them as a non-competitive monopoly. In fact, under provisions of U.S. anti-trust legislation, officers of DeBeers are not permitted to enter the U.S.A. Since the Canadian Combines Investigation Act is similar to the U.S. Anti-Trust Act, there is some reason to believe that DeBeers might be restricted in the way it conducts business in Canada.

Nonetheless, it is generally conceded that the cartel has been as good for the purchasers of diamonds as it has been for those who mine them. Since it was established in 1930, the CSO has maintained stability in the marketplace and prevented diamonds from experiencing the ups and downs in value that normally affect most commodities.

The rationale is that gem diamonds (not including those used in industrial applications) are a luxury item, and those who purchase them expect them to retain their value or increase in value. The CSO has maintained stability by withholding or releasing diamonds in response to changes in market demand. Consequently, the price of gem diamonds has increased at a real rate of two per cent a year over inflation since World War II. To maintain demand for diamonds, DeBeers spends approximately US$170 million a year on advertising, promoting the notion that "A diamond is forever."

Producers who contract with the CSO agree to sell their entire production, at prices that equal 90 per cent of the current CSO selling price. For producers, this arrangement provides certainty of sales, cash flow and a price that is consistently higher than they could obtain on the open market. Also, they benefit from DeBeers' advertising. The contract terms include a quota, which is the portion of the CSO's total purchases that will be made from individual contract-holders. This establishes each producer's market share, and any attempt by one producer to increase its share will harm other producers.

Some newer participants in the diamond business are refusing to be tied to the CSO through contractual arrangements and are causing the CSO to be less a monopoly and more like a producers cooperative. It remains to be seen what effect this might have on the stability of the marketplace.

For those diamond producers owned by DeBeers or contracted to the CSO, their products flow from mines to customers in what is called the "Diamond Pipeline."

The first step is to sort the newly mined, rough diamonds. This usually occurs at the mine site, but some producers send the unsorted rough diamonds (called rough) to the CSO in London. The rough sorted at the mine site is also sent to the CSO, and then the sorted diamonds from all producers are mixed together and kept in "buffer stock" until a decision is made to release them to the marketplace.

Rough diamonds are sorted into 5 000 grades according to clarity, colour, weight and crystal shape/structure. A rarity premium is assigned to stones at the top end of the grading system. [illegible] rough diamonds become highly desired end-products. Owing to natural imperfections and material loss in the cutting process, approximately 100 million carats of natural rough diamond production yields 15 million carats of polished [illegible]

[illegible] 165 individuals are invited to attend a [illegible] SO headquarters. Here, these people (called "Sightholders") are presented with boxes of diamonds (called [illegible] The average price per box is $ [illegible] million. Sightholders can either pay the price or reject the entire [illegible] on the contents or the price. To a

large extent, the contents reflect what each Sightholder requested a few weeks earlier, but CSO staff also reserve the right to add types of diamonds that they want to remove from inventory and believe the individual sightholder can sell profitably.

Sightholders take their purchases to the open market, resort them and either polish and sell them, or resell them to others who will polish and sell them to customers.

The CSO maintains interests in, and gathers information from, virtually every aspect of the diamond business. One way it does this is through research and development that benefits the entire industry. The CSO conducts research in prospecting, mining, recovery, sorting, cutting and polishing of rough diamonds, and also tries to counteract the perceived threat of simulants and synthetics.

The term "economic rent" is used in the diamond business to mean the difference between the price the market will pay for the resource and the amount it costs the producer to bring the resource to market, including a return on investment. Owing to the way the CSO functions, the mine-mouth price for rough diamonds is kept at a level that maximizes the economic rent for producers. This stable price is accomplished by controlling supply and simultaneously creating demand, and the price is usually high enough to encourage extensive exploration by companies that are not currently part of the cartel.

Diamond Sales

Preliminary estimates show that global diamond sales in 1994 were at least $45 billion. This compares with sales in 1980 of $20 billion.

All indications suggest that demand for gem diamonds will continue to rise for the following reasons:

- the world population is rising;
- new markets are opening in East Asian countries, such as Pakistan, Turkey and the Persian Gulf states;
- the percentage of the population under the age of 15 in these new markets is twice that of traditional markets;
- long-term economic growth should be strong in traditional markets; and
- many people in traditional market countries are soon expected to receive windfall gains from inheritances.

Mine Economics

Diamond mines are expensive to build ($300–500 million), but most have access to kimberlite pipes that can provide a steady supply up to 25 years.

Knowing the grade per ton of ore and the extraction costs is not enough information to decide whether a diamond mine will be economic. For example, experience shows that most mines average one carat of diamonds (five carats equal one gram) for each tonne of ore. This amounts to 0.2 grams a tonne. Based on weight alone, this is far below the most marginal gold mine or precious metal mine. The average gem content of a diamond mine is 30 per cent. Since gem grades represent 90 per cent of the total value of all production, there will be approximately 0.06 grams of gem diamonds for each tonne of ore, or less than one part per million. Combining gem content, yield per tonne and revenue, it has been estimated that any new Canadian diamond mine must generate a minimum return of US$40 a tonne.

Based on the information that has been made public about diamond exploration in NWT, it is believed that Canada will soon have at least one diamond mine, perhaps as early as 1997. According to BHP/Diamet, the company expected to have the first operational mine in NWT, the size of the deposit plus the gem content and quality could easily make it a world-class mine. It is likely it would be tied with the Orapa mine in Botswana as the fifth largest in the world.

Conclusions

Since the BHP/Diamet mine would be the first in Canada, new opportunities could arise in associated activities. For example, there would be a need for skilled sorters. The structure of the CSO and the existence of diamond manufacturing centres in countries, such as Belgium and Israel, would make it difficult to establish a viable diamond polishing and manufacturing industry in Canada. Nonetheless, other countries have overcome these obstacles and established secondary diamond industries, and it is conceivable that Canada could do the same.

Publication

Vandenberg, R. 1996. Canadian Diamond Market Study. Maple Leaf Resources. 195 pp. In press.

Fort Chipewyan Granite as an Aggregate Source

Alberta Geological Survey, Edmonton

Project C3.1

One of the outstanding geological features of northeast Alberta is a red granitic pluton measuring 24 km by 6.5 km that

lies northwest of Fort Chipewyan. Various investigations throughout the 1970s indicated that this rock would be suitable as ornamental building stone, and a quarrying operation was subsequently begun in 1988 to produce standard-size building blocks measuring 1.2 m × 1.5 m × 2.7 m. Unfortunately, this proved to be impossible because the blocks broke into smaller pieces, apparently because of the close spacing of joints and fractures in the rock.

Attempts are continuing to produce acceptable blocks, and it has been suggested that the waste rock from the quarrying operation be crushed and sold in various existing markets. An alternative proposal suggests that a new operation be started for the sole purpose of producing crushed granite.

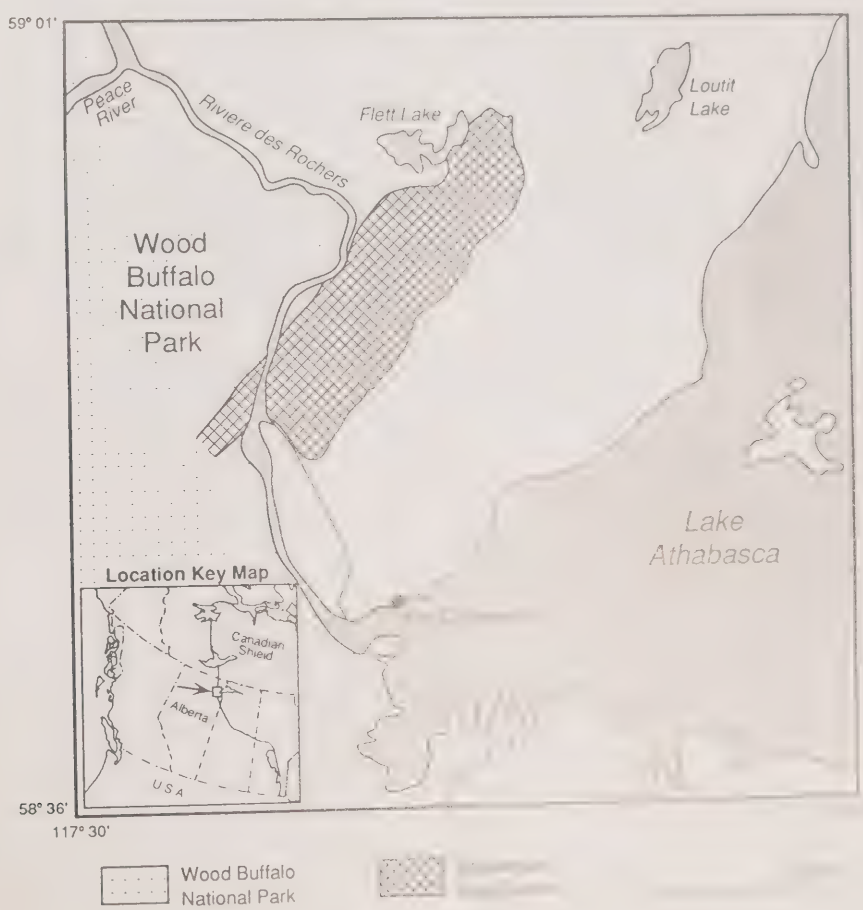
The objective of this study was to investigate the various markets for crushed granite products and determine if some type of granite-crushing operation would be economically viable.

Material Characteristics

The Chipewyan Red Granite, as it is known, is noted for its rare, deep-red colour. It has a medium-grained texture, is locally fine grained and massive to faintly lineated. The granite is mostly pink to red potash feldspar (34 per cent), plus 31 per cent quartz, 29 per cent plagioclase, 2.7 per cent biotite, 0.9 per cent chlorite, and some minor minerals. Given the spacing of the joints and defects in the raw rock, it has been estimated that the maximum size of blocks available from one sector of the pluton would be 0.2 m × 0.75 m × 1.0 m.

Potential Markets

Blocks or pieces smaller than those used for dimension stone could be used in tile, curbing, facing blocks or slabs for walls, small burial headstones and lapidary memorabilia. These markets were not examined in this study since they do not use crushed stone.



Location of Chipewyan Red Gra

Instead, the focus was on products such as agglomerated granite tile, landscape rock, bridge deck topping, poultry grit, exposed aggregate panels, roofing granules, railway ballast and roadstone.

Agglomerated Granite Tiles

Agglomerated granite tiles are made by mixing graded granite chips with cement, polyester or epoxy, and pouring the mixture into molds. The finished blocks are sawn into slabs, which are then cut into tiles of various sizes. The tiles can then be polished to varying degrees and used on floors, walls, stairs and window or door sills. In Alberta, approximately 40 000 such tiles are sold each year and all are made from agglomerated marble.

Landscape Rock

Granite and other rocks are crushed and used on walkways or as ground cover around trees and shrubs. Currently, white quartzite and dolostone are used as landscape rock in Alberta, and they sell for approximately $65/tonne in bulk. Total demand is estimated to be 200 tonnes a year. Crushed Chipewyan Red Granite should be an appealing option in this market.

Concrete Deck Topping

Aggregate-resin mixtures are applied to the surfaces of concrete bridges, overpasses and the decks of parking structures to counteract penetration by chemicals and water, and abrasion from traffic. Granite easily meets the specifications for these applications, but Chipewyan Red Granite would have to compete with other established materials. Currently, the price paid is $250 a tonne, and future demand in Alberta is projected to be 100 tonnes a year.

Poultry Grit

Among the various supplements used in premixed feed for poultry, granite grit is included to help release nutrients in the crop of birds. In Alberta, the annual demand is approximately 50 tonnes, and the total Canadian demand is 1 000 tonnes. Currently, poultry grit sells for $90 a tonne.

Exposed Aggregate Concrete

Coloured aggregate is used in precast panels that are attached to the vertical faces of concrete buildings. The demand in Alberta varies from 100 to 250 tonnes a year, and the price ranges widely from approximately $5 a tonne for local aggregate to $225 a tonne for imported, coloured materials.

Roofing Granules

Fine rock granules are imbedded into asphalt roofing shingles to provide some protection from fires and to impede attack of the asphalt by ultraviolet radiation. Approximately 30 000 tonnes of various types of stone chips are used in Alberta annually at a cost of $22 a tonne. It has been estimated that demand in Alberta for Chipewyan Red Granite would be approximately 300 tonnes a year.

Railway Ballast

Railroad companies use various types of crushed materials as ballast on their railways, and the sources of most must be located close to the railway to reduce haulage costs. Approximately 163 000 tonnes a year are used in Alberta, and the cost is $8 a tonne. Experience has shown, however, that igneous rocks are more suitable than granite.

Roadstone

Currently, crushed gravel is used on Alberta roadways as a support material for asphalt. If this material were replaced by Chipewyan Red Granite, the market could be as much as 848 000 tonnes a year.

Economic Calculations

Various economic models were constructed to calculate the viability of crushed granite operations. Each model represented one of several options. For example, one option involved the use of waste granite from an existing dimension-stone quarry. In another, a quarry operation designed specifically to extract and crush granite was evaluated. Sub-options evaluated the economics of making various products from the crushed material. All the various assumptions and calculations are available on a computer disk, and Lotus 1,2,3 software was used.

Results

The economic models showed that the most promising option involved making agglomerated tiles, and this could be profitable by using either waste granite from an existing operation or by using a new quarry operation for the specific purpose of recovering crushed granite. It was assumed that 800 000 tiles a year would be manufactured, the plant would cost $5 million to build, and the tiles could be sold in the Edmonton market for $7.50 each.

The models also showed that waste granite could be used profitably for making poultry grit, landscape rock, concrete deck topping and exposed aggregate concrete products.

Publication

Scafe, D. 1994. Preliminary Study of the Economic Feasibility of Producing Crushed Stone from Fort Chipewyan Red Granite. Open File Report 1994-02. Alberta Geological Survey. 26 pp., map.

Mineral Aggregate Database and Deposit Map Series

Alberta Research Council, Edmonton

Project C3.7

Sand and gravel (collectively known as mineral aggregate) is the most valuable, non-energy mineral produced in Alberta, generating raw material having an annual value of $150 million. Also, the sand and gravel industry is by far the largest employer in Alberta's mineral sector. Despite this status, however, there is no common database of information on the sand and gravel resource which various government departments could use when making resource-management decisions. This means some resources are probably being underused or developed inappropriately. Worse still, some valuable resources have likely been made inaccessible ("sterilized") by other land uses without resource managers ever knowing that the resource exists.

To help rectify the situation, this project was undertaken to prepare a mineral aggregate database, which could then be used to construct resource maps or be integrated with data on other land-use issues, such as proposed sites for solid waste disposal or forestry development.

Methodology and Results

The database was constructed by digitizing approximately 2 000 sand and gravel deposit outlines that already existed at Alberta Geological Survey. Then, additional data received from various government departments were digitized and entered into the database.

This information was then used to prepare 15 1:250 000 scale maps. These maps cover approximately one-third the total area of Alberta and represent a variety of situations, including the extreme north, the extreme south, remote areas, highly developed urban areas and highly developed agricultural areas. The 15 maps coincide with the following NTS designations: 84B, 84C, 84F, 84K, 84L, 84M, 83A, 83B, 83G, 83H, 83M, 83P, 82H, 82I and 73E.

A final report that describes the preparation and use of the maps and related tables will be released as an Alberta Research Council Open File.

The database and maps have already generated considerable interest. Several draft maps were presented at the CIM conference in May 1994. Also, a presentation was made at the B.C. Aggregate Forum and Workshop on March 30, 1995. It was hosted by the British Columbia Geological Survey. Data have already been used by Alberta Geological Survey and Alberta Agriculture and Rural Development.

Publication

Edwards, D. In press. The Geology, Exploration Characteristics and Resource Potential of Sand and Gravel Deposits in Alberta, Canada. To be published as a special volume on mineral aggregates by British Columbia Energy, Mines and Petroleum Resources.

Review of Alberta Limestone Production, Marketing, Distribution and Future Development Possibilities

Holter Geological Services, Ferndale, Washington, U.S.A.

Project C3.6

Limestone is one of the most valuable minerals commonly used in the world. It is a principal component in Portland cement, is the feed material for lime, is used in the manufacture of various chemicals and fertilizer, and is being used increasingly to remove noxious substances in air pollution-control systems.

Substantial limestone deposits are located in the Foothills and Cordillera in western Alberta, allowing industries based on limestone to have become well established in the province. While limestone extraction and processing have been good for Alberta, the objective of this study was to identify new opportunities so the industry can grow.

Limestone — Defined

Limestone is a sedimentary rock formed from the shells of small marine animals, and is essentially pure calcium carbonate. When limestone is reacted with clay or shale at high temperatures, Portland cement is formed. If burned, limestone evolves carbon dioxide and leaves a residue of lime (or quicklime), which is calcium oxide. When combined with water, lime forms

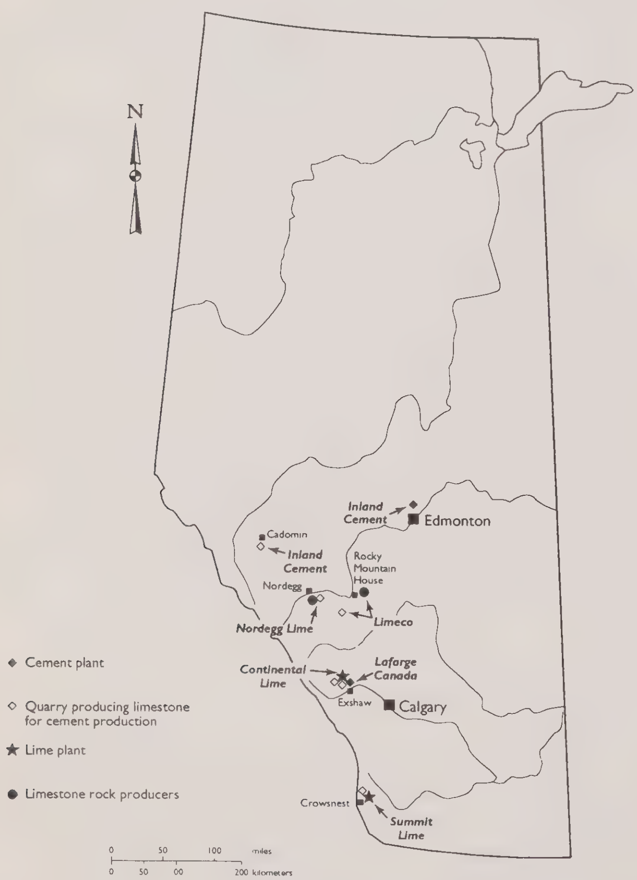
slaked lime (calcium hydroxide), an important agent in neutralizing acidic media. All these substances and their uses comprise Alberta's limestone industry.

Study Methodology

The status of known limestone resources was reviewed, and then the current limestone-producing and limestone-using industries in Alberta were surveyed and described in detail. This was followed by an investigation of possible new uses for limestone and whether they could be supplied from Alberta sources.

Limestone Sources

Alberta's limestone resources are found in strata of the Devonian Palliser Formation or the Mississippian Livingstone Formation. The principal outcrop zones are located within the Cordilleran and Foothills regions along the western edge of the province and along systems of the Athabasca and Clearwater rivers in northeast Alberta. Detailed geological maps of known limestone-bearing formations are found in the study report.



Alberta cement, lime and limestone rock producers.

Limestone Production

Limestone is extracted from major quarries at Exshaw (near Banff) and Cadomin. The Exshaw operation, owned by Lafarge Canada, also includes a cement plant. Limestone from the Cadomin quarry is transported to Edmonton, where it is made into cement by Inland Cement. Altogether, approximately two million tonnes of limestone are mined annually, and virtually all of it is used to make cement.

Two lime operations owned by Continental Lime are active in Alberta: at Exshaw and in the Crowsnest Pass. Collectively, they produce approximately 250 000 tonnes a year.

Rock products from limestone are produced by Limeco Products at Rocky Mountain House and by Nordegg Lime at Nordegg, west of Rocky Mountain House. These products include aggregate, rip rap and dimension stone.

Each of these operations is described in detail in the study report.

Consumers of Limestone and Lime

While cement production consumes most limestone, a relatively new market shows potential for growth. It involves using limestone in flue gas desulphurization processes to reduce sulphur dioxide emissions. It is anticipated that new power plants using conventional technology or retrofits of existing plants may include this air pollution-control technology.

Small quantities of limestone have been used in the manufacture of asphalt roofing, glass bottles, fibreglass insulation and paints. The mineral is also used as a dusting agent and in water treatment processes.

Approximately 20 000 tonnes of lime are used annually at the British Columbia Sugar Refining Company in Taber, Alberta. This company produces sugar from locally grown sugar beets, and uses an on-site facility to convert limestone to the slaked lime that is needed in the sugar-making process.

Alberta's growing pulp and paper industry also consumes lime. The pulping process uses lime to remove impurities from by-product streams, and calcium carbonate is used in papermaking. Annual quantities consumed by this industry were not available.

Concern is growing over the acidification of some Alberta lakes by acid rain that originates outside the province. At least two lakes in Alberta have been treated with lime to neutralize their acidity.

Future Developments

When compared with other minerals, limestone does not command high prices. Therefore, it cannot be shipped economically over long distances. This means that most new markets for Alberta limestone will likely be in Alberta. Currently, the industry is mature, stable and competitive, and the resource is sufficiently abundant at most locations to accommodate projected growth in current products. Regarding new market niches, demand for limestone rock products is expected to grow, and the continued evolution of the pulp and paper industry may require new quarries to be opened in northern Alberta. Environmental concerns may lead to increased use of limestone in air pollution control, and more lime use in neutralizing acidified lakes.

Publication

Holter, M.E. 1994. A Review of Alberta Limestone Production, Marketing, Distribution and Future Development Possibilities. Holter Geological Services. 85 pp.

Evaluation of Leonardite Resources of Alberta

Retread Resources Ltd., Sherwood Park

Project C3.2

Leonardite, humalite and humate are naturally occurring materials, and all contain humic acid. This makes them desirable for agriculture, reclamation and the drilling industry, but Alberta's known resources are not being as well used as they might be. This study was undertaken to provide an overview of Alberta's resource and some indication of markets for this material.

Material Descriptions

Leonardite, humalite and humate are formed by natural weathering of low-rank coals and carbonaceous sediments, and are usually found near known coal deposits. Although all three contain humic acid, each is distinctly different from the other. For example, leonardite is oxidized lignite and is found in North Dakota, Texas and Saskatchewan. It has a higher oxygen content than lignite (28–29 per cent versus 19–20 per cent), but resembles coal in appearance. Because it is a naturally occurring material originally derived from plants, its humic acid content varies widely: 33–42 per cent for North Dakota leonardite, 28 per cent for the Texas material and 84 per cent for Saskatchewan leonardite.

A similar material exists in Alberta, but it has been given another name — humalite — because it is the product of weathered sub-bituminous coal or carbonaceous shale. Its humic acid content ranges from 15 to 80 per cent, and averages 60 per cent.

Humate, found in New Mexico, is also weathered sub-bituminous coal, but its humic acid content is lower than in humalite: 2–56 per cent, with an average of only 17 per cent.

Uses for Humalite and Similar Products

The most profitable use for humalite and similar products in the past has been as a drilling fluid additive, but this market has shrunk in recent years as drilling activities declined in North America. As drilling fluid additives, these materials help maintain the desired viscosity and acid level (pH) of drilling mud, which aids overall control of a drilling operation.

Agricultural and reclamation uses are now overtaking those in drilling as the most important for humalite and similar materials. Largely, their value derives from an ability to add organic material to soil in the form of humic acid. In this regard, they are well-known as effective conditioners for saline and alkaline soils. Complex interactions — that are not well understood — also make them especially suitable for reclaiming soils that have been contaminated with hydrocarbons. Also, organic farming, which is a growth industry and requires that no chemical fertilizers, herbicides or pesticides be used, relies on humic acid as a soil conditioner.

Humalite Deposits

There are two known deposits of humalite in Alberta: Forestburg and Sheerness. Total measured resources amount to 118 000 tonnes, with speculative resources perhaps as high as 2 million tonnes.

The Forestburg deposit was mined commercially from 1957 to 1983, but it shut down when drilling activities declined in Alberta. A stockpile of unprocessed humalite remains at the plant site, but the source from a nearby sub-bituminous coal mine is no longer available.

At the Sheerness coal mine, 118 000 tonnes have been located beneath approximately two metres of overburden, and considerably more may be present at other locations on the mine property. It has been estimated that the Sheerness humalite could be recovered for approximately $35 a tonne. Allowing for research, packaging, hauling and other costs, this material could be sold in Alberta for approximately $0.31/kg.

This is a fraction of the cost of imported leonardite or humate and it contains significantly more humic acid. For example, New Mexico humate is sold in Alberta for $2.20/kg.

Western Canadian humalite and leonardite areas.

Conclusions

Considering Alberta's extensive agricultural activities and a growing need for mine-site and well-site reclamation, it was estimated that sales of Alberta-supplied humalite could amount to 45 000 tonnes a year.

For this to happen, it is believed that a product awareness program is needed, along with better definition of the resource base and more research on humalite use in reclamation. Of equal importance, organic food sales are increasing rapidly in California and the Pacific Northwest states. These areas ought to be targeted as future market areas.

Publication

Hoffman, G.L., D.J. Nikols, S. Stuhec and R.A. Wilson. 1993. Evaluation of Leonardite (Humalite) Resources of Alberta. Alberta Research Council Open File 1993-18. Retread Resources Ltd. 45 pp.

Economic Analysis of Extracting Calcium Chloride and Magnesium Chloride from Alberta's Brines

Donald B. Cross & Associates Limited, Calgary

Project C3.3

Geoscience studies have indicated that economic quantities of certain salts may be present in brines found at various locations in Alberta. In this study, an investigation was made to determine the economic viability of recovering calcium and magnesium chlorides from these brines.

Methodology

The study covered the following aspects:

- current markets for calcium chloride and magnesium chloride;
- the production methods for each;
- major North American producers and their share of the market;
- historical review of price performance;
- capital and operating costs of facilities to recover the two chemicals and the anticipated level of profitability; and
- future changes in the marketplace.

Calcium Chloride

Calcium chloride is used for dust suppression, road conditioning and ice removal. It is also used as a desiccant and as an accelerator to hasten concrete hardening.

A single Dow Chemical plant in Ludington, Michigan supplies approximately two-thirds of the total U.S. production of calcium chloride, and a General Chemical Canada Ltd. plant in Amherstburg, Ontario is the largest supplier in Canada. Although current U.S. production is only 62 per cent of capacity, Canadian producers export approximately 100 000 tonnes a year to the U.S.A.

The Dow Chemical plant extracts natural brines, but a California firm makes synthetic calcium chloride by reacting hydrochloric acid with limestone. In Amherstburg, calcium chloride is made as a by-product of sodium carbonate production.

The Michigan brines extracted by Dow Chemical contain approximately 75 000 mg/L of calcium. This compares with approximately 16 000 mg/L of calcium in brines extracted by a

General Chemical plant at Drumheller and 125 000 mg/L of calcium in brines used by Ward Chemical at Calling Lake, Alberta. While the Drumheller plant (and another owned by General Chemical at Brooks) produce only small quantities of a 25 per cent solution of calcium chloride, the production capacity of two Ward Chemical plants (Villeneuve and Fort Saskatchewan), plus a Tiger Calcium plant at Smith totals 175 000 tonnes a year. The product is sold as a 32–40 per cent solution, and the plants are operating well below capacity.

Historically, calcium chloride prices have kept pace with increases in raw materials prices.

Magnesium Chloride

In the U.S.A., magnesium compounds are produced from sea water, lake brines and well brines. A plant in Quebec makes magnesium chloride from magnesite ($MgCO_3$). Magnesium chloride is usually produced as an intermediate step in the electrolytic production of magnesium metal or in the production of synthetic magnesia and other compounds.

In Alberta, a one-step process for producing anhydrous magnesium chloride was demonstrated at the Magnesium Co. of Canada plant at Aldersyde, but that plant has since been shut down. In this process, magnesite is reacted with chlorine gas in the presence of carbon monoxide in a packed-bed reactor at 900°C. The magnesium chloride product is then used as the feedstock in electrolytic cells to produce metallic magnesium.

Magnesium chloride prices have increased faster than those of the chemical industry as a whole.

Alberta Extraction Plant

An economic analysis was done for a new plant that would recover both calcium chloride and magnesium chloride from Alberta brines. It included a plant capacity capable of satisfying Alberta demand and that of Alberta's trading area. Also, the magnesium-recovery capacity had to be sufficient to satisfy the feedstock requirements of the mothballed magnesium smelter at Aldersyde. This amounted to 28 406 tonnes a year of magnesium chloride plus 46 480 tonnes a year of calcium chloride.

It was estimated that the capital cost of this plant would be $52.6 million, and the annual operating cost would be $22.4 million. Assuming an annual before-tax profit of $160 000, the fixed costs could not be amortized over 20 years. This means the investment is not economic, but could become economic if sales rose by 25 per cent or operating costs fell 25 per cent.

Conclusions

While the North American market is oversupplied in both chemicals, and poor economics do not favour a new plant at this time, it was concluded that changes in these conditions might represent an opportunity for Alberta. For example, the two preferred feedstocks for the magnesium smelter at Aldersyde — magnesite and magnesium chloride — are probably present in sufficient quantities in Alberta. This needs to be confirmed by a targeted geological investigation of Alberta's magnesite resources. Also, calcium chloride has begun to be used in newsprint deinking and the manufacture of sodium chlorate, which is a precursor to chlorine-free bleaching agents used in the pulp and paper business. Since both these activities are growing in Alberta, they might help justify a major brine-extraction operation.

Publication

Donald B. Cross & Associates Limited. 1993. Economic Analysis of Extracting Calcium chloride and Magnesium Chloride from Alberta Brines. Alberta Research Council. Open File Report 1993-19. 37 pp.

Whitehorse Mining Initiative

Whitehorse Mining Initiative Secretariat, Ottawa

Project M92-08-002

While many challenges facing Canada's mining industry are global in nature and beyond domestic control, some can be addressed by those parties who have a stake in the industry. At a September 1992 meeting in Whitehorse of the federal and provincial mines ministers, The Mining Association of Canada proposed that a new strategic vision for the industry needed to be developed, and it required the cooperation of all affected parties. Consequently, the Whitehorse Mining Initiative was established, and representatives of five sectors of society subsequently participated in discussions. They represented the mining industry, senior governments, labour unions, aboriginal peoples and the environmental community.

On September 13, 1994, the discussions held among these representatives culminated in the Leadership Council Accord of the Whitehorse Mining Initiative. It contains a vision statement, 16 principles, 70 goals and a commitment to follow-up action.

The principles that were agreed to by all parties concern the following aspects of the mining industry:

- business climate;
- financing;
- taxation;
- overlap and duplication;
- government services;
- environmental protection;
- planning and environmental assessment;
- use of information and science in environmental decision-making;
- land use and land access;
- protected areas;
- certainty of mineral tenure;
- attracting and retaining skilled workers;
- maximizing community benefits from mining;
- aboriginal lands and resources;
- aboriginal involvement in the mining industry; and
- open decision-making process.

Details about each principle and goal are found in the 69-page final report listed below. It is available on request from:

The Mining Association of Canada
Suite 1105, 350 Sparks Street
Ottawa, Ontario
K1R 7S8

or

Mineral Policy and Planning Division
Natural Resources Canada
460 O'Connor Street, Room 1212
Ottawa, Ontario
K1A 0E4

Publication:

Leadership Council Accord. 1994. Whitehorse Mining Initiative. Final Report. 69 pp. Ottawa, Ontario

IGWG Native Representatives

Rodney Gardiner (Ile-a-la Cross), and Lyle Bear (La Ronge)

Project C3.4

The *Inter-Governmental Working Group (IGWG) Sub-committee on Aboriginal Participation in the Mining Industry of Canada* promotes aboriginal involvement in the Canadian mining industry. It also provides historical and current information on this subject. These aims are best achieved by involving aboriginals in sub-committee activities.

This project provided financial assistance to two aboriginals who are familiar with western Canadian mining activities so they could attend relevant conferences and meetings.

Rodney Gardiner, an employee of Cogema Resources Inc. at Cluff Lake Saskatchewan, attended the IGWG Sub-committee meeting during the annual convention of the Prospectors and Developers Association of Canada, which was held March 27, 1993.

Lyle Bear, Northern Liaison Officer of Cogema/Cluff Mining, attended the IGWG Sub-committee meeting on November 9 and 10, 1993 in Vancouver.

Both these representatives contributed to the Annual Report of the IGWG Sub-committee on Aboriginal Participation in the Mining Industry. This report was prepared for the mines ministers. They also participated in other sub-committee activities as required.

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This project was cost-shared with the British Columbia, Saskatchewan and Manitoba Mineral Development Agreements.

Alberta PAMD Worldwide Web Server

Alberta Geological Survey, Edmonton

Project C3.9

No research program would be complete without mechanisms for disseminating the research results to those people who need them. One way to do this is to create a homepage on the World Wide Web of the Internet.

In this project, reference documents and an index to available information were created and placed on a WWW homepage established solely for the Canada-Alberta Partnership Agreement on Mineral Development (PAMD) (or MDA). Persons accessing this homepage will find a logo, a statement of purpose for the MDA, a list of contributors, links to a projects list and links to other on-line resources arising from the MDA. Also available are project lists that identify geoscience, technology development and economic development projects. Users will find a location map or photo, a brief description or abstract, a list and description of the project products, and the contact person or agency for each project. Also found there is a newsletter and a map index to the projects list. The resolution of this map is equivalent to that of one NTS map sheet.

The homepage can be found at:

- http://www.energy.gov.ab.ca/ags/mda/pamdhome.html

PUBLIC INFORMATION

Public information activities were designed to enhance awareness of the mineral sector's contribution to Alberta's economy. This includes a recognition of the roles and contributions made by both levels of government to the mineral sector through the Agreement.

Information was disseminated by various means, with emphasis on appropriate coordination of federal and provincial initiatives.

The following activities were completed:

- a visual identity for the MDA program was developed, including stationery, report covers, geoscience scale cards and stickers;
- a program brochure was produced;
- a media list was developed, and persons on this list subsequently received news releases and other information regarding MDA progress and participation by MDA researchers in various public forums;
- advertisements promoting the MDA were placed in trade publications;
- a newsletter (*Minerals Update*) was developed and issued;
- a conference display booth was developed, materials were produced for its panels, and it was set up at various conferences;
- a "mid-term" review of the MDA program was written and distributed;
- in cooperation with the Alberta Association of Professional Engineers, Geologists and Geophysicists, rock and mineral kits were produced for school students;
- 50 copies of *Alberta Miners — A Tribute* were purchased and made available to promote the MDA; and
- funding was provided to help scientists attend the Canadian Institute of Mining, Metallurgy and Petroleum Annual General Meeting in Toronto in 1994.

EVALUATION AND ADMINISTRATION

Both the federal and Alberta governments provided an administrative structure to support the Management Committee and technical committees, and to provide financial information about the MDA program. Also, both governments provided project management and legal support for contracts.

Each government conducted separate internal reviews and audits of its portion of the MDA funding, and found that the program was operationally and financially satisfactory. An overall evaluation of the effectiveness of government geoscience programs is being carried out by the Centre for Resource Studies at Queen's University in Kingston, Ontario. This project, *Economic Impact of Government Geoscience Programs,* was funded by the federal component of the MDA.

Economic Impact of Government Geoscience Programs

Centre for Resource Studies, Queen's University, Kingston, Ontario

Project C5.1

In the past, government-funded geological surveys have played an important, but largely unquestioned, role in developing the mineral sector. Like virtually all government programs these days, geoscience programs are undergoing financial scrutiny. Thus, the Centre for Resource Studies at Queen's University was contracted to perform an independent assessment of the geoscience component of the MDA.

Methodology

The project involves three tasks:

- compile, document and analyze previous work done in this area;
- develop a methodology which takes into account the long term and dynamic nature of the mineral supply; and
- test the methodology using some case studies.

Results

At the close of the MDA program, work was still under way, and individuals from the Alberta Geological Survey, Geological Survey of Canada and the University of Alberta were participating in the project.

While the literature on previous work is somewhat limited, there is sufficient material for developing the desired methodology, especially when combined with the information in the Centre's database of exploration activity.

A final report was scheduled to be released in March 1996.

Appendix I — Acknowledgements

Members of MDA Committees

Currently serving on Management Committee:

P. Precht, Co-Chair, Alberta Department of Energy

D. Luff, Alberta Department of Energy

A. Clark, Co-Chair, Natural Resources Canada

G. Mossop, Natural Resources Canada

Currently serving on Geoscience Technical Committee:

J. Boon, Co-Chair, Alberta Geological Survey

R. Macqueen, Co-Chair, Geological Survey of Canada, Calgary

D. Currie, Industry Advisor, Alberta Chamber of Resources

R. Olson, Alternate Industry Advisor, Alberta Chamber of Resources

Currently serving on Technology Development Technical Committee:

M. Torres, Co-Chair, Alberta Department of Energy

R. MacDonald, Co-Chair, CANMET

E. Yildirim, Industry Advisor, Alberta Chamber of Resources

Currently serving on Economic Development Technical Committee

K. Rehaag, Co-Chair, Alberta Department of Energy

P. Coolen, Co-Chair, Natural Resources Canada

R. Laing, Industry Advisor, Inland Cement

Currently serving on Public Information Technical Committee:

J. Dodd, Co-Chair, Alberta Department of Energy

P. Coolen, Co-Chair, Natural Resources Canada

Currently serving on Evaluation/Administration Technical Committee:

J. Kleta, Co-Chair, Alberta Department of Energy

P. Coolen, Co-Chair, Natural Resources Canada

Secretariat:

J. Kleta, Alberta Department of Energy

P. Coolen, Natural Resources Canada

K. Wood, Alberta Department of Energy

Acknowledgement

The following individuals served the MDA in various capacities, and their contributions to its success are hereby acknowledged.

For participating in the Management Committee: N. MacMurchy and M. Day, of Alberta Department of Energy; and G. Peeling of Natural Resources Canada. For participating in the Geoscience Technical Committee: R. Richardson of Alberta Geological Survey and D. Richardson of the Geological Survey of Canada. For participating in the Technology Development Technical Committee: G. Bird and E. Isaacs of Alberta Research Council; and D. Brown and C. Edwards of CANMET. For participating in the Public Information Technical Committee: J. McCracken and R. Cronin of Alberta Department of Energy; and G. Kaiser, M. Silenzi and S. Peets of Natural Resources Canada. For participating in the Secretariat: M. Das of Natural Resources Canada.

For contributions to various administrative activities of the MDA: J. Fraser-Holdsworth, V. Chymko and L. Mitchell of Alberta Department of Energy; and C. Pelletier, L. Pelletier, D. Chisholm, R. Hayman, C. Moore, K. Doyle, C. Weishaupt and S. Elliott-Meadows, all of Natural Resources Canada.

Appendix II — Background on the Surveys

Alberta Geological Survey

The Alberta Geological Survey (AGS), part of the Alberta Department of Energy, provides geoscience information needed for environmentally responsible resource development in Alberta. Established in 1921 to help the province discover its mineral base, the AGS carried out the first research activities of the Alberta Research Council. Today, it conducts geological mapping and resource characterization in industrial and metallic minerals; operates a computer database on Alberta mineral deposits and occurrences; and maintains the Minerals Core Research Facility. Other activities include hydrogeology; studies of coal and oil sands deposits; evaluation studies for the disposal of liquid waste; and data management and dissemination.

Geological models, core studies and mineralogy characterization, along with log analysis, electronic databases and computer-aided mapping, are services provided in support of industry. The AGS offers expert advice and information services, and works with industry in a variety of ways. These include data sharing, mutual assistance during field work, consortia and specialized contract work if the required competence is not available in the private sector.

Non-energy minerals are expected to play a key role in Alberta's economic future. Systematic collection of data on hundreds of mineral deposits and occurrences is currently being undertaken by the AGS with the objective of constructing appropriately linked, automated databases from which maps can be produced as required.

The AGS has established a world reputation for excellence in oil sands geology. Fifteen years of systematically characterizing Alberta's oil sands deposits have resulted in an unparalleled knowledge of the geology of the deposits at Cold Lake, Athabasca and Peace River.

The AGS is becoming increasingly involved in environmental geoscience studies. Its work on the disposal of liquid waste influenced the selection of the injection aquifer for the Swan Hills hazardous waste disposal site and the assessment of residual water disposal in the Cold Lake oil sands and heavy oil area. Also, AGS compilation maps are increasingly directed toward support for land-use planning.

AGS data have influenced the exploration, production, marketability and development of sound land-use policies for Alberta coal. The AGS also provides leadership in coal-bed methane geological research in Alberta.

The Geological Survey of Canada

Throughout its 150-year history, the Geological Survey of Canada (GSC) has conducted exploration, mapping, analysis and the development of technology vital to the discovery of resources. This work — still carried forward today — has been a foundation for Canada's mineral and petroleum industries.

The Geological Survey of Canada office in Calgary is a regional centre of the GSC. It is an important source of information and expertise on the geology, geophysics, geochemistry and resource potential of sedimentary basins in western and northern Canada. These basins cover approximately one-third of Canada's landmass and contain most of its known oil, gas and coal resources, as well as important deposits of minerals.

GSC Calgary has specialists in all the main geoscience disciplines. These scientists have access to sophisticated analytical and data-processing equipment and extensive geoscience archives. Consequently, they and their colleagues in Ottawa are well-positioned to carry out projects under the MDA.

The foremost mission of the GSC has been to chart and interpret the geology of the vast Canadian landmass. This began with its surface features, and today extends tens of kilometres below the earth and sea beds off Canada's coasts. For a century and a half, the Survey's maps and reports directed prospectors and others to areas where they were most likely to make commercial discoveries.

Recent GSC projects include:

- the National Geoscience Mapping program (NATMAP), an effort of governments, universities and industry to improve the quality and completeness of Canada's geological maps and databases.
- LITHOPROBE, one of the most extensive geoscience research efforts ever undertaken anywhere. Scientists use a variety of techniques to reveal the geology beneath the surface of the Canadian landmass and the surrounding sea beds, to depths of 50 kilometres and more. This work explores the composition of the continent, and the creation of mountains, plains and seas. It has benefitted mining and petroleum exploration. The GSC is a major partner in this joint venture of governments, universities and industry.
- regional mapping of the Arctic islands. This mapping has identified geological formations that may hold major quantities of oil and gas.
- detailed mineral deposit studies in Northwest Territories, Newfoundland, Nova Scotia, New Brunswick and Quebec. These studies can help to reverse the decline in Canada's known reserves of minerals.

The GSC has helped explorationists in both the mining and petroleum industries to find and evaluate new resources. A pioneer in airborne geophysics, the GSC has continued to be an innovator in the mining geophysics and aeromagnetics industries.

GSC support for the geophysics industry has enabled Canadian firms to capture two thirds of the world market for geophysical mining equipment and software.

Most importantly, the Survey exchanges information and participates in joint ventures with private companies and provincial and territorial surveys. For example, in partnership with major oil companies, the GSC carried out a high-resolution aeromagnetic survey covering one-half of Alberta. A diamond exploration company also joined in this project.

As part of its long-term strategy, the GSC assists mining companies in advancing their knowledge of Canada's most important mineral deposits and extending the lifespans of mines and communities that depend on those deposits.

The GSC is also available to help industry solve problems and expand its exploratory capabilities. As a national institution, the Survey brings a breadth of geoscientific experience to industry. A national database of geological information is maintained so that expertise the GSC gains in one part of the country can be applied to other regions.

Appendix III — Financial Tables

PROVINCIAL EXPENDITURES

Supported projects		1992-93	1993-94	1994-95	1995-96 (forecast)	Total expenditures
GEOSCIENCE						
M92-04-002	Geological Mapping, Prospecting and Sampling of the Southern Alberta Rift in Southwest Alberta to Identify Potential Targets for Metallic Mineral Exploration	185 000	0	0	0	185 000
M92-04-003	Study of the Hydrogeochemistry of Northern Alberta with Specific Reference to the Possible Occurrences of Zn-Pb Deposits	50 000	0	0	0	50 000
M92-04-004	Assessment of the Potential of Co-product Minerals and Metals in Alberta Oil Sand Deposits	100 700	0	0	0	100 700
M92-04-005	Mineral Information System	182 874	112 475	74 800	115 700	485 849
M92-04-006	Reconnaissance Mineral and Geochemical Survey with Emphasis on Northern Alberta	137 000	145 000	145 000	0	427 000
M92-04-007	Evaluation of Mineralization Potential of Selected Areas of Northeastern Alberta	135 000	135 000	135 000	0	405 000
M92-04-008	Mapping and Resource Exploration of the Tertiary Formations of Alberta	36 000	45 000	35 000	25 000	141 000
M92-04-009	Analysis and Cataloguing of Precambrian Shield Rock Samples in Support of Government and Industry Mapping and Exploration Programs	51 000	0	0	0	51 000
M92-04-011	Evaluation of the Potential for the Recovery of Industrial Minerals from Alberta Brines	100 000	100 000	100 000	0	300 000
M92-04-012	Geoscience Coordination, Public Open Houses and Final Publication of Provincially Funded Projects	60 500	57 000	71 500	174 050	363 050
M92-04-013	Mineral Resource Mapping of Main Mountain Corridors	32 000	53 375	42 000	21 000	148 375
M92-04-014	Regional Synthesis and Characterization of Industrial Limestones in Alberta	26 200	41 140	49 700	0	117 040
M92-04-015	Commodity Profiling of Principal Industrial and Metallic Minerals in Alberta	27 000	0	0	0	27 000
M93-04-031	Investigation of Potential Paleoplacers in the Cretaceous Strata of the North Saskatchewan River Watershed	0	69 130	0	0	69 130
M93-04-032	Analysis of Palaeozoic Core Data for the Evaluation of Potential Pb/Zn Deposits in Northeast Alberta	0	43 938	0	0	43 938
M93-04-034	Reconnaissance Structural-Stratigraphic Study of the Southern Alberta Rift in Southwest Alberta	0	96 000	0	0	96 000
M93-04-035	Surficial Geology Mapping & Quaternary Stratigraphy of the Peace River & HIgh Level-Fort Vermillion Areas of N. Alberta	0	30 000	30 000	0	60 000
M93-04-036	Mineral Aggregate Commodity Analysis	0	35 000	17 000	0	52 000

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PROVINCIAL EXPENDITURES (continued)

	Supported projects	*1992-93*	*1993-94*	*1994-95*	*1995-96 (forecast)*	*Total expenditures*
M93-04-037	Regional Synthesis of the Structural and Stratigraphic Setting of Alberta to Assist Industry in their Search for Diamondiferous Diatremes	0	89 000	0	0	89 000
M93-04-038	The Mineral Deposits Potential of the Marguerite River Area	0	100 000	0	0	100 000
M94-04-039	Preliminary Stratigraphy Tests to Support Mineral Exploration: Northern Alberta	0	0	0 *	0	0
	Sub-Total: Geoscience	**1 123 274**	**1 152 058**	**700 000**	**335 750**	**3 311 082**
TECHNOLOGY DEVELOPMENT						
M93-06-002	Development of an Expanded Light Weight Plaster Structural Type Building Product for Agricultural or Light Weight Industrial Use	0	27 430	0	0	27 430
M93-06-003	Establishing Diamond Exploration Sample Processing Methodology and Facilities for Alberta	0	66 128	0	0	66 128
M93-04-004	Development of Enhanced Methodology for the Analysis of Indicator Minerals in Potential Diamond Bearing Ores in Alberta	0	85 330	0	0	85 330
M94-06-011	Diamond Separation by Selective Adsorption	0	0	94 999	0	94 999
M94-06-014	Novel Technology for Gold Recovery from Alberta Placer Deposits, Phase II	0	0	79 959	0	79 959
M95-06-016	Study of the Environmental Impact of Envi-Tech Fine Gold Recovery Process	0	0	0	18 942	18 942
	Sub-Total: Technology Development	**0**	**178 888**	**174 959**	**18 942**	**372 789**
ECONOMIC DEVELOPMENT						
M93-08-002	Whitehorse Mining Initiative	0	7 875	0	0	7 875
M94-08-011	Diamond Market Study	0	0	80 000	0	80 000
	Sub-Total: Economic Development	**0**	**7 875**	**80 000**	**0**	**87 875**
PUBLIC INFORMATION						
M92-10-002	Communications Plan	5 055	6 000	4 000	40 000	55 055
	Sub-Total: Public Information	**5 055**	**6 000**	**4 000**	**40 000**	**55 055**
ADMINISTRATION / EVALUATION						
M92-12-02	MDA Evaluation	0	0	0	0	0
M92-12-03	Administration, Planning and Implementation	10 782	3 000	956	5 000	19 738
M92-12-04	Audit of Alberta-Implemented Projects	0	0	0	0	0
	Sub-Total: Administration/Evaluation*	**10 782**	**3 000**	**956**	**5 000**	**19 738**
	Total Provincial Expenditures	**1 139 111**	**1 347 821**	**959 915**	**399 692**	**3 846 539**

* The Alberta Department of Energy avoided the use of MDA program funds to administer the program. Estimated costs of Alberta Energy's support for administration, audit and evaluation functions over the life of the program come to $355,000.

FEDERAL EXPENDITURES

	Supported projects	1992-93	1993-94	1994-95	1995-96 (forecast)	Total expenditures
GEOSCIENCE						
C1.11	Tectonic Evolution of Precambrian Shield of Northeastern Alberta, EMR	125 377	150 604	110 326	45 543	431 850
C1.12	Metallogenic Studies for U-polymetallic Mineralization of the Athabasca Basin and Adjacent Area, EMR	33 519	55 115	19 409	0	108 043
C1.13	Quaternary Geology & Till Geochemistry	81 783	129 137	87 786	55 062	353 768
C1.14	Airborne Gamma-ray Spectrometer-Magnetic-VLP Plus Interpretation & Follow-up	0	207 584	29 943	0	237 527
C1.15	Geochemical Surveys	0	185 892	10 185	0	196 077
C1.16	Data Integration	29 894	27 079	131	35 768	92 872
C1.21	Mineral Potential, Metamorphism and Petrogenesis of Crowsnest Volcanics	37 257	41 133	0	0	78 390
C1.31	Kimberlite, Mineralogy, Petrology, Geochemistry	19 206	43 743	28 805	27 337	119 091
C1.32	Geochemical and Mineralogical Reconnaissance	144 901	48 192	10 379	0	203 472
C1.33	Aeromagnetic Survey	155 973	150 800	0	0	306 773
C1.34	Stratigraphic Drilling in N. Alberta	0	0	0	51 300	51 300
C1.35	Shaftesbury Formation Geochemistry & Stratigraphy	0	0	0	100 000	100 000
C1.41	Brine Resources of Alberta	0	31 364	22 973	40 666	95 003
C1.51	Orientation Studies	5 107	17 397	13 164	0	35 668
C1.61	Coordination & Publication	31 890	33 592	24 791	59 357	149 630
	Sub-Total: Geoscience	**664 907**	**1 121 632**	**357 892**	**415 033**	**2 559 464**
TECHNOLOGY DEVELOPMENT						
C.2.0.1	Project Management	0	22 731	19 379	6 000	48 110
C2.1.1	Heavy Minerals Recovery from Syncrude Centrifuge Plant Tailings	0	0	321 250	390 800	702 050
C2.1.2	Microwave Smelting of Low Rank Coal and Oxide Minerals	0	0	31 333	0	31 333
C2.2.2	Clay Carbo-Chlorination Screening Study	0	0	317 200	0	317 200
C2.3.1	Novel Technology of Gold Recovery from Alberta Placer Deposits	0	190 320	33 284	0	223 604
C.2.3.2	Engineering Design and Preliminary Feasibility of Envi-Tech Adsorption Technology for Fine Gold Recovery	0	0	0	43 037	43 037
C2.3.3	Novel Gold Phase III	0	0	0	20 800	20 800
C2.3.4	Diamond Recovery Selective Adsorption	0	0	0	52 000	52 000
	Sub-Total: Technology Development	**0**	**213 051**	**722 446**	**502 637**	**1 438 134**

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FEDERAL EXPENDITURES (continued)

	Supported projects	*1992-93*	*1993-94*	*1994-95*	*1995-96 (forecast)*	*Total expenditures*
ECONOMIC DEVELOPMENT						
C.3.1	Fort Chipewyan Granite as an Aggregate Source	0	20 000	0	0	20 000
C.3.2	Evaluation of Leonardite Resources of Alberta	20 000	0	0	0	20 000
C.3.3	Economic Analysis of Extracting Calcium Chloride and Magnesium Chloride from Alberta's Brines	17 000	0	0	0	17 000
C.3.4	IGWG Native Representative	548	409	0	0	957
C3.5	DSS Charges	0	1 000	2 000	3 000	6 000
C.3.6	Review of Alberta Limestone Production, Marketing, Distribution, and Future Development Possibilities	0	20 000	0	0	20 000
C.3.7	Mineral Aggregate Data Base and Deposit Map Series	0	50 500	26 247	23 000	99 747
C.3.9	Alberta PAMD World Wide Web Server	0	0	0	18 000	18 000
	Sub-Total: Economic Development	**37 548**	**91 909**	**28 247**	**44 000**	**201 704**
PUBLIC INFORMATION						
C.4.1	Logo	1 631	0	0	0	1 631
C.4.2	Hardware and Graphics	8 737	0	0	0	8 737
C.4.3	Photographic Image	700	0	0	0	700
C.4.5	Travel	1 704	0	0	0	1 704
C.4.6	Partnership Stationery	394	0	0	0	394
C.4.7	Feature Story	589	0	0	0	589
C.4.9	Public Information	13 033	0	0	0	13 033
C.1.10	Partnership Communications	0	13 460	0	0	13 460
C.4.11	Legacy Education Initiative	0	300	0	0	300
C.1.12	Administration and Baseline	0	26 559	16 207	0	42 766
C.4.13	CIM Conference (Toronto '94)	0	0	9 700	0	9 700
C.4.14	Other Conferences, Travel	0	0	4 186	0	4 186
C.4.15	French Newsletter	0	0	0	0	0
C.4.16	Public Information — Conference MDA booth Exhibit	0	0	0	12 000	12 000
C.4.17	Public Information	0	0	0	0	0
	Sub-Total: Public Information	**26 788**	**40 319**	**30 093**	**12 000**	**109 200**

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FEDERAL EXPENDITURES (continued)

	Supported projects	*1992-93*	*1993-94*	*1994-95*	*1995-96 (forecast)*	*Total expenditures*
ADMINISTRATION / EVALUATION						
C.5.1	MDA Evaluation	0	0	0	30 000	30 000
C.5.2	Coordination, Planning & Implementation	22 528	71 107	31 258	50 106	174 999
C.5.3	Financial Administration	5 199	16 648	14 217	10 343	46 407
C.5.4	MDA Audit	0	0	0	25 000	25 000
	Sub-Total: Administration/Evaluation	**27 727**	**87 755**	**45 475**	**115 449**	**276 406**
	TOTAL	**756 970**	**1 554 666**	**1 184 153**	**1 089 119**	**4 584 908**

Total Expenditures, Canada-Alberta Partnership on Minerals	**1 896 081**	**2 902 487**	**2 144 068**	**1 488 811**	**8 431 447**

Additional Information

Persons wishing to obtain or view reports, maps and other information resulting from the Canada-Alberta Partnership on Minerals are directed to the following.

- For Alberta geoscience project results, as well as federal and Alberta economic development project results, and non-confidential federal and Alberta technology development project results, contact:

  Alberta Geological Survey Information Sales
  7th Floor, North Petroleum Plaza
  9945 – 108 Street
  Edmonton, Alberta
  T5K 2G6
  Telephone: (403) 422-3767
  Fax: (403) 422-1918
  Internet: http://www.energy.gov.ab.ca/ags/ ags1/ags.html

- Federal geoscience project results are available at:

  GSC Bookstore/Librairie de la CGC
  Geological Survey of Canada
  601 Booth Street
  Ottawa, Ontario
  K1A 0E8
  Telephone: (613) 995-4342
  Fax: (613) 943-0646
  Internet: gsc_bookstore@gsc.emr.ca

  GSC/CGC (Calgary)
  3303 – 33 Street NW
  Calgary, Alberta
  T2L 2A7
  Telephone: (403) 292-7030
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Alberta ENERGY

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